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Techniques adopted to control emission (particularly NOx, HC, CO, PM) from CI engine using diesel/biodiesel as a fuel: A review

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ABSTRACT

Many studies have reported that exhaust from biodiesel fuel has higher oxides of nitrogen, whereas hydrocarbon (HC) and smoke emission are significantly lower than that of diesel fuel. In diesel engines, NOx formation is a highly temperature-dependent phenomenon and takes place when the temperature in the combustion chamber exceeds 2000K. In this paper there are different types of technique discussed to control emission.

KEYWORDS

Diesel engine;
Biodiesel;
Emission;
Injection pressure;
Injection timing;
Variable stroke length;
EGR.

INTRODUCTION

The number of vehicles (2 wheelers, Cars, LCVs, HCVs) has increased rapidly in India and globally. Nearly 10 million vehicles of different categories are being produced annually.

Similarly, in year 2006-07, India produced 1.4 million vehicles whereas automotive vehicles produced by China and USA stood at 5 million and 10 million, respectively. It is estimated that by the year 2025 AD, the number of vehicles on Indian roads shall be more than 1 billion which will so severely aggravate the scenario in terms of fuel consumption and environmental pollution[1].

Out of all emission, oxides of nitrogen and particulate matter (PM) are the most significant in diesel engines due to high flame temperature and diffusive combustion in the combustion chamber. Since nitric oxides (NOx) and PM emissions from current diesel technologies are close to the limits prescribed by regulations and these are likely to be even more stringent in the near future, these two emissions will be critical factors in the development of new diesel engines. For example, Euro 5 will reduce NOx and PM emission limits for passenger cars from 0.25 and 0.025g/km to 0.18 and 0.005g/km, respectively (emissions tested over the NEDC) chassis dynamometer procedure. Moreover, Euro 5 will consider both mass and number based PM emission limits, although the measurement method for particle number must previously be established. For the other regulated emission, carbon monoxide (CO) and total hydrocarbon (THC), no further development in engines seem to be necessary to meet future limits[2].

The estimated emissions from motor vehicles in Chennai in 2005 were 431, 119, 46, 6 and 4575 tons/days respectively for CO, VOC, NOx, PM and CO_2. It is observed from the results that air quality in Chennai has degraded. The estimation revealed that two and three-wheelers emitted about 64 percent of the total CO emissions and heavy-duty vehicles accounted for more than 60 percent and 36 percent of the NOx and PM emissions respectively. About 19 percent of total emissions were that of start emissions. The estimated health damage cost of automobile emissions in Chennai is Rs.6488.16 million (US $ 162.20 million)[3]. Mumbai also faces a serious air pollution problem caused, in part from vehicles. Between 2000 and 2002, annual average PM10 was approximately 80g/m^3 (World Bank, 2005), higher than in Mexico City.1 In many ways, however, Mumbai is more fortunate than other Indian cities. It has an extensive rail and bus system and a much smaller vehicle fleet than Delhi, a city of comparable size and income. The problem facing Mumbai is to reduce emissions from diesel trucks and buses, as well as taxis and auto-rickshaws and to prevent rapid growth of the private vehicle fleet[4]. In developing countries the air quality crisis in cities is often attributed in large measures (40-80%) to vehicular emissions. This rapid growth of the urban population also brings with it an increasing demand for energy-based goods and services. Urban India depicts a picture of metamorphosis. The feudal towns have changed to industrial cities, cities into metropolises, and metropolises into megalopolises. Owing to the expanding economic base, there is an influx of people migrating from the rural areas and urban fringes to the core city in search of a better life. The economic statistics reveal an in-creasing contribution of urban areas to the GDP (gross domestic product). These had contributed only 29% of the GDP in 1950-51, which increased to 47% in 1980-81 and to 60% in 2000-01[5]. Diesel engines are mainly used in many fields, transport of passenger and cargo, industrial and agricultural activities. Petroleum fuels are being widely used in diesel engines and the demand for same is increasing multifold that cannot be met for a long time. Any shortfall shall adversely affect the energy sector and hence the need for alternative fuels. In addition, pollutants are emitted by combustion of petroleum based fuels in diesel engines. Pollutants from diesel engines include carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxides (SOx), Oxides of nitrogen (NOx) and particulate matter (PM). NOx and PM are two the primary pollutants of diesel engines[6].

NOx is a generic term for mono-nitrogen oxides namely NO and NO_2, which are produced during combustion at high temperatures. At ambient temperatures, oxygen and nitrogen do not react with each other. However, in an internal combustion engine, high temperatures lead to reactions between nitrogen and oxygen to yield nitrogen oxides. In the presence of excess oxygen, nitric oxide will be converted to nitrogen dioxide[7].

In order to meet the stringent automotive emission regulations, increasing number of diesel vehicles around the world use catalytic converters. Diesel exhaust after treatment applications includes Diesel Oxidation Catalyst (DOC), Diesel Particular Filter (DPF) and NOx absorber. In order to enable after treatment operations, diesel engines commonly require supplemental energy to raise the otherwise relatively low exhaust temperature[8].

Diesel engine is the major contributor to NOx and particulate emission (PM) due to high temperature and pressure combustion. The spraying of water in combustion chamber is one of the strategies to control oxides of nitrogen (NOx). The main intention is to reduce peak temperature in the combustion zone. It is believed that the water could lower the gas temperature by means of water evaporation and thus deceasing in the rate of thermal-NOx formation by Zeldovich mechanism reaction. NOx are also precursors to ozone (O_3) formation, which could jeopardize the human health and vegetation as well. Finally, NOx contributes to acid deposition, damaging the vegetation and aquatic system[9].

The combustion of petroleum based fuels emits emissions that threaten wild and human life. These combustion products adds to global warming, a major problem faced by world today. The global warming is caused by emissions like carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NOx). In all this transport sector has played a role. Its contribution to global warming potential have increased from year by year and now bigger than those of the domestic and industrial sector, while it highly constitutes the total emissions of this pollution type[10]. Due to this many studies have been carried out to find bio-fuels to substitute diesel. The effect of compression ratio, swirl ratio, coolant temperatures, combustion chamber shapes, spray angle, nozzle hole diameter, multi-injection, and others on DI diesel emissions has been also extensively studied. Changes in injection timings change the position of piston and cylinder pressure and temperature at injection. Consequently, some important influencing factors for emissions such as ignition delay, adhered fuel, and squish are changed. Retarded injection timings showed significant reduction in diesel NOx[11,12].

EMISSION NORMS

To minimize the impact of emission the government has progressively formulated stringent norms, some of chart are given in TABLE 1 and TABLE 2. TABLE 3 lists the standards being followed in India and the region in which these are applicable. TABLE 4 enumerates the technology option available to achieve that norm.

TABLE 1 : Emission standards for diesel truck and bus engines, g/kwh

Year	Reference	CO	HC	NOx	PM
1992	-	17.3-32.6	2.7-3.7	-	-
1996	-	11.20	2.40	14.4	-
2000	Euro I	4.5	1.1	8.0	0.36*
2005+	Euro II	4.0	1.1	7.0	0.15
2010+	Euro III	2.1	0.66	5.0	0.10

***0.612 for engines below 85 KW**
+earlier introduction in selected regions

TABLE 2 : Emission standards for light duty diesel vehicles, g/km

Year	Reference	CO	HC	HC+NOx	NOx	PM
1992	-	1.73-32.6	2.7-3.7	-	-	-
1996	-	5.0-9.0	-	2.0-4.0	-	-
2000	Euro 1	2.72-6.90	-	0.97-1.70	-	0.14-0.25
2005+	Euro 2	1.0-1.5	-	0.7-1.2	-	0.08-0.17
2010+	Euro 3	0.64 0.80 0.95	-	0.56 0.72 0.86	0.50 0.65 0.78	0.05 0.07 0.10
2010≠	Euro 4	0.50 0.63 0.74	-	0.30 0.39 0.46	0.25 0.33 0.39	0.025 0.04 0.06

TABLE 3 : Indian emission standards (4-wheel vehicles)

Standard	Reference	Date	Region
India 2000	Euro 1	2000	Nationwide
Bharat stage II	Euro 2	2001	NCR*, Mumbai, Kolkata, Chennai
		2003-04	NCR*, 10 Cities+
		2004-05	Nationwide
Bharat stage III	Euro 3	2005-04	NCR*, 10 Cities+
		2004-10	Nationwide
Bharat stage IV	Euro 4	2010-04	NCR*, 10 cities+

Emission standards for new heavy-duty diesel engines-applicable to vehicles of GVW>3,500 kg are listed in TABLE 1. Emissions are tested over the ECE R49 13-mode test (through the Euro II stage).

TABLE 4

Level of emission norms	Technology options
Euro I/India 2000	Retarted Injection timing Open/re-entrant bowl, Intake, exhaustand combustion optimization FIP~700-800 bar, low sac injectors High swirl Naturally aspirated
Euro II/Bharat Stage II	Turbocharging Injection pressure>800 bar, moderate swirl High pressure inline/rotary pumps, injection rate control VO nozzles Re-entrant combustion chamber Lube oil consumption control Inter-cooling (optional, depends on specific power), EGR (may be required for high speed car engines) Conversion to CNG with catalytic converter
Euro III/Bharat stage III	Multi valve, Low swirl- high injection pressure>120 bar Rotary pumps, pilot injection rate shaping Electronic fuel injection Critical lube oil consumption control Variable geometry turbocharger (VGT) Inter-cooling Oxycat & EGR CNG/LPG High specific power output
Euro IV/Bharat Stage IV	Particulate trap NOx trap On board Diagnostics system Common rail injection-injection pressure>1600 bar Fuel cell CNG/LPG

Emission standards for light-duty diesel vehicles (GVW≤3,500 kg) are summarized in TABLE 2. Ranges of emission limits refer to different classes (by reference mass) of light commercial vehicles; compare the EU light-duty vehicle emission standards page for details on the Euro 1 and later standards. The lowest limit in each range applies to passenger cars (GVW≤2,500 kg: up to 6 seats).

For 2-and 3-wheelers, Bharat Stage II (Euro 2) is be applicable from April 1, 2005 and Stage III (Euro 3) standards would come in force preferably from April 1, 2008, but not later than April 1, 2010.

National Capital Region Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahmedabad, Pune, Surat, Kanpur and Agra. The test cycle has been the ECE+EUDC for low power vehicles (with maximum speed limited to 90 km/h). Before 2000, emissions were measured over an Indian test cycle. Engines for use in light-duty vehicles can be also emission tested using an engine dynamometer.

The above standards apply to all new 4-wheel vehicles sold and registered in the respective regions. In addition, the Nation Auto Fuel Policy introduces certain emission requirements for interstate buses with routes originating or terminating in Delhi or the other 10 cities.

For 2-and 3-wheelers, Bharat stage II (Euro) will be applicable from April 1, 2005 and stage III (Euro) standards would come in force preferably from April 1, 2008, but not later than April 1, 2010.

On October 6, 2003, the National Auto Fuel Policy has been announced, which envisages a phased program for introducing Euro 2-4 emission and fuel regulations by 2010.

The above standards apply to all new 4-wheel vehicles sold and registered in the respective regions. In addition, the National Auto Fuel Policy introduces certain emission requirements for interstate buses with routes originating or terminating in Delhi or the other 10 cities[13].

MECHANISM OF EMISSIONS

NOx formation

A major hurdle in understanding the mechanism of formation of NOx and its control is that combustion is highly heterogeneous and transient in diesel engines. While NO and NO_2 are lumped together as NOx, there are some distinctive differences between these two pollutants. NO is a colourless and odourless gas, while NO_2 is a reddish-brown gas with pungent odour. Both gases are considered toxic, but NO_2 has a level of toxicity that is 5 times greater than that of NO. Although NO_2 is largely formed from oxidation of NO, attention has been given on how NO can be controlled before and after combustion.

NO is formed during the post flame combustion process in a high temperature region. The principal source of NO formation is the oxidation of the nitrogen present in atmosphere air. The nitric oxide formation chain reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures reached during the combustion process as shown below,

$$\mathbf{N_2+O} \rightarrow \mathrm{NO+N}$$

$$\mathrm{N+O_2} \rightarrow \mathbf{NO+N}$$

$$\mathbf{N+OH} \rightarrow \mathrm{NO+N}$$

Chemical equilibrium consideration indicates that for burnt gases at typical flame temperature, NO_2/NO ratios should be negligibly small. While experimental data show that this is true for spark ignition engines, engine exhaust NO_2 can be 10 to 30% of total exhaust emissions of oxides of nitrogen in diesel engines. A plausible mechanism for the persistence of NO_2 is as follows. NO formed in the flame zone can rapidly converted to NO_2 via reactions such as

$$\mathbf{NO+HO_2} \rightarrow \mathrm{NO_2+OH}$$

Subsequently, conversion of this NO_2 to NO occurs via

$$\mathbf{NO_2+O} \rightarrow \mathbf{NO+\ O_2}$$

Unless the NO_2 formed in the flame is quenched by mixing with cooler fluid. The local atomic oxygen concentration depends on molecular oxygen concentration as well as local temperatures. Formation of NOx is absent at temperatures below 2000 k. Hence any technique, that can keep the instantaneous local temperature in the combustion chamber below 2000 k, will be able reduce NOx formation.

Carbon monoxide (CO)

Carbon monoxide, a colorless, odorless, poisonous gas, is generated in an engine when it is operated with a fuel-rich equivalence ratio. When there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO. Not only is CO considered an undesirable emission, but it also represents lost chemical energy that was not fully utilized in the engine. CO is a fuel and can be combusted to supply additional thermal energy:

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 + Heat$$

Maximum CO is generated when an engine runs rich, such as when starting or when acceleratating. Even when the intake air-fuel mixture is stoichiometric or lean, some CO may be formed CI engines that operate in a lean manner overall generally have very low CO emissions.

Carbon dioxide (CO_2)

At moderate levels of concentration, carbon dioxide is not considered an air pollutant. However, it is considered a major greenhouse gas and at higher concentration, is a major contributor to global warming. CO_2 is the major component of the exhaust in the combustion of any hydrocarbon fuel. Because of the growing number of motor vehicles, along with factories and other sources, the amount of carbon dioxide in the atmosphere continues to grow. The higher concentration of carbon dioxide in atmosphere, along with other greenhouse gases, create a thermal radiation shield, this shield reduces the amount of thermal radiation energy allowed to escape from the earth, raising slightly the average earth temperature. The most efficient way of reducing the amount of CO_2 is to burn less fuel[14].

TECHNIQUES FOR EMISSION REDUCTION

Exhaust gas recirculation

EGR is a useful technique for reducing NOx formation in the combustion chamber. Exhaust consists of CO_2, N_2 and water vapours mainly. When a part of this exhaust gas is re-circulated to the cylinder, it acts as dilutant to the combusting mixture. This also reduces the O_2 concentration in the combustion chamber. The specific heat of the EGR is much higher than fresh air, hence EGR increases the heat capacity of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber,

$$\%EGR = \frac{\text{VOLUME OF EGR}}{\text{TOTAL INTAKE CHARGE INTO THE CYLINDER}}$$

Another way to define the EGR ratio is the use of CO_2 concentration.

$$\text{EGR ratio} = \frac{[CO_2]\text{intake} - [CO_2]\text{ambient}}{[CO_2]\text{exhaust} - [CO_2]}$$

Three popular explanations for the effect of EGR on NOx reduction are, increased ignition delay, increased heat capacity and dilution of the intake charge with inert gases. The ignition delay hypothesis asserted that because EGR causes an increase in ignition delay, it has the same effect as retarding the injection timing. The heat capacity hypothesis states that the addition of the inert exhaust gas into intake increases the heat capacity (specific heat) of the non-reacting matter present during the combustion. The increased heat capacity has the effect of lowering the peak combustion temperature. According to the dilution theory, the effect of EGR on NOx is caused by increasing amounts of inert gases in the mixture, which reduces the adiabatic flame temperature. This technique is effective but increases fuel combustion by 10-15%, which necessitates the use of more effective NOx reduction techniques. At high loads, it is difficult to employ EGR due to deterioration in diffusion combustion and this may result in an excessive increase in smoke and particulate emissions. At low loads, unburnt hydrocarbons contained in the EGR would possibly re-burn in the mixture, leading to lower unburnt fuel in the exhaust and thus improved brake thermal efficiency. Apart from this, hot EGR would raise the intake charge temperature, thereby influencing favorably combustion and exhaust emissions[15]. Exhaust gas recirculation (EGR) was extensively applied to initiate low temperature combustion (LTC) mode at medium and low load conditions. An intake throttling valve was implemented to increase the differential pressure between the intake and exhaust in order to increase and enhance the EGR. Simultaneous reduction of NOx and soot was achieved when the ignition delay was prolonged by more than 50% from the case with 0% EGR at low load conditions. Ultra-low engine-out levels of NOx and soot were achieved in a narrow region of operation between 55 and 65% EGR[16].

Thermal converters

Some engines are equipped with thermal converters as a means of lowering emissions. Thermal converters are high-temperature chambers through which the exhaust gas flows. They promote oxidation of the CO and HC that remain in the exhaust.

$$CO + \frac{1}{2}O_2 \rightarrow CO_2$$

For this reaction to occur at a useful rate, the temperature must be held above 700°C. Now consider the reaction.

$$C_xH_y + z\,O_2 \rightarrow x\,CO_2 + y\,H_2O$$

Where $z=x+0.25y$.

The above reaction needs a temperature above 600°C for at least 50 milliseconds to substantially reduce HC. Thermal converter should also be large enough to provide adequate residence time of the exhaust gases to promote the occurrence of these secondary reactions. Most thermal converters are essentially an enlarged exhaust manifold connected to the engine immediately outside the exhaust ports. This is necessary to minimize heat losses and keep the exhaust gases from cooling to non reacting temperatures.

Catalytic converters

The most effective after treatment for reducing engine emissions is the catalytic converter found on most automobiles and other modern engines of medium or large size. CO and HC can be oxidized to CO_2 and H_2O in exhaust systems and thermal converters if the temperature is held at 600-700°C. If certain catalysts are present, the temperature needed to sustain these oxidation processes is reduced to 250-30°C. A catalyst lowers the energy needed for the chemical reaction and is not consumed in the reaction and so functions indefinitely unless degraded by heat, age, contaminants or other factors. Catalytic converters generally made of stainless steel, are mounted in the flow system through which the exhaust gases pass through.

Generally, catalytic converters are called three-way converters because they are used to reduce the concentration of CO, HC, and NO_x in the exhaust.

Inside the container the exhaust gas flow through a porous ceramic structure passages. Some converters use loose granular ceramic with the gas passing between the packed spheres. Volume of the ceramic structure of a converter is generally about half the displacement volume of the engine. This results in a volumetric flow rate of exhaust gas such that there are 5 to 30 changeovers of gas each second, through the converter. Catalytic converters for CI engines need large flow passages because of the solid soot in the exhaust gases.

The surface of the ceramic passages contains small-embedded particles of catalytic material that promote the oxidation reactions in the exhaust as it passes. Aluminum oxide is the base ceramic material used for most catalytic converters. Alumina can withstand the high temperatures, it remains chemically neutral, it has very low thermal expansion, and it does not thermally degrade with age. The catalytic materials most commonly used are platinum, palladium, and rhodium.

Palladium and platinum promote the oxidation of CO and HC as in equations, with platinum active in the hydrocarbon reaction. Rhodium promotes the reaction of NO_x in one or more of the following reactions.

$$NO + CO \rightarrow \frac{1}{2}N_2 + CO_2$$

$$2NO + 5CO + 3H_2O \rightarrow 2NH_3 + 5CO_2$$

$$2NO + CO \rightarrow N_2 + CO_2$$

Also often used is cerium oxide, which promotes the so-called water gas shift

$$CO + H_2O \rightarrow CO_2 + H_2$$

This reduces CO by using Water vapor as an oxidant instead of O_2, which is very important when the engine is running rich[14]. Using copper plate catalytic converter is designed and development for a volume of 1000 cm^3. The experiment is carried out on four-stroke single cylinder CI engine. The optimum values of exhaust emissions found at full load are HC (35.2ppm), CO (0.1%), and NOx (87ppm). The conversion efficiency of the catalytic converter is calculated and it is found that it is increasing with increase in number of copper plates. The total numbers of copper baffle plates tried inside the converter shell are 28 out of which 20 numbers of plates found to give optimum results with maximum conversion efficiency for HC (55.44%), CO (62.96%) and NOx (40.41%) emission at full load. With increasing the number of copper plates beyond 20 does not show any improvement in emission reduction hence it is concluded that the 20 numbers of copper plates are optimum for emission reduction[17].

Using advance injection strategies

Different combustion modes with multiple-injection strategies were studies for pure diesel and biodiesel (soybean) fuels. The injection strategies included a small first injection with early pre-TDC timing and a main injection at or after TDC. The first injection fuel quantity was fixed at1.5mm^3 for both fuels. The injection timing was changed to achieve different combustion modes. The first injection timing changed from -40 CAD to -20 CAD ATDC by a step of 10 CAD. The main injection timings timing were chosen at TDC and 10 CAD ATDC. Under a certain injection strategy with retarded main injections, it is possible to have up to 34% lower NOx emissions for B100 than B0[18]. To reduce the NOx emission from the diesel engines employing bio diesel blend as fuel, the injection timing of fuel is altered by either addition or removal of shims in the pump. The effect of changing the injection timing on BSEC, Brake Thermal Efficiency, CO, HC and NO emissions are studied at different injection timings such as 18, 21, 24, 27 and 30 CA bTDC. From the experiments it is found that on retarding the injection to 18 CA bTDC from 24 CA bTDC, the original injection timing, the NOx emission reduced to about 35% while advancing to 30 CA bTDC, the NOx increased by 25%. The BSEC, CO, HC have been found to increase by about 3%, 12.65% and 10% respectively on retarding to 18 CA bTDC while decrease by 6.27%, 32%, and 14.44% respectively on advancing the injection to 30 CA bTDC. The brake thermal efficiency is reduced by 3.08% on retarding to 18 CA bTDC whereas it is improved by 5.09% on advancing the injection timing to 30 CA bTDC[19].

Fuel injection and injection pressure

Injection timings from 15 deg before top dead center (BTDC) to top dead center (TDC) and injection pressures from 20MPa to 120MPa were tested. In emissions, exhaust odor, irritation, aldehydes, total hydrocarbon and hydrocarbon component are compared for different injection timings and injection pressures condition, Injection timings where main combustion takes place very close to TDC are found to slow minimum odors emissions, Moderate injection pressures (60-80MPa). And this will show lower emissions including odor and irritation due to proper mixture formation. Before the injection pressure of 40MPa, and over 80MPa, emissions become worse. The THC becomes 30-40% lower at the injection pressure of 40MPa and above than that at 20MPa at all injection timings. Combustion analysis is performed by taking cylinder pressures after engine warm-up for different injection pressures and analyzing cylinder temperatures and heat release rates. Cylinder pressures and temperatures are gradually deceased when injection timings are retarded. Ignition delay becomes shortest at 5-10 deg BTDC injection timing. The peak cylinder pressure and temperature are increased with higher injection pressures. The shortest ignition delay and minimum emissions is found at around 60MPa of injection pressure[20].

Variable stroke length and constant compression ratio

The effect of variable stroke length technique on the emissions of a four-stroke, water-cooled direct injections diesel engine was studied with the help of experimentally verified computer software designed mainly for diesel engines. The emission levels were studied over the speed range (1000rpm to 3000rpm) and stroke lengths (120mm to 200mm) and were compared with those of the original engine design[18]. The simulation results clearly indicate the advantages and utility of variable stroke technique in the reduction of the exhaust emission levels. A reduction of about 10% to 75% was achieved for specific particulate matter over the entire speed range and bore-to-stroke ratio studied. Further, a reduction of about 10% to 59% was achieved for the same range. As for carbon dioxide, a reduction of 0% to 37% was achieved. On the other hand, a less percent change was achieved for the case of nitrogen dioxide and nitrogen oxides as indicated by the results. This study clearly shows the advantage of VSE over fixed stroke engines. This study showed that the variable stroke technique proved a good way to curb the diesel exhaust emissions and hence helped making these engines more environmentally friendly[21].The advantage of varying the stroke length and compression ratio may be noticed that the engine’s indicated power has registered an increase up to 62% over that of the ordinary constant-stroke engine. There was a change in the engines indicated specific fuel consumption at large bore-to-stroke ratios of about -6 to +4%. And the engine carbon-monoxide emission increased by 2.5-1.5% and that for nitric oxides increased by 2-58% at large bore-to-stroke ratios[22].

CONCLUSION

Sustained efforts are being made to reduce emission and maximize the utilization of environment-friendly energy source. The emissions particularly NOx, CO, PM etc are very harmful to the environment. Several feasible options for control of these emissions have been employed and the reported works in the literature has been discussed. These six techniques are Exhaust Gas Recirculation (EGR), Thermal Converter, Catalytic converters, Using advance injection strategies, Fuel injection and injection pressure and Variable stroke length and constant compression ratio. Each technique has some advantages and limitations. Among them fuel injection and injection pressure technique have been found to be quite effective from the design point of view. They are effective in controlling the generation of harmful emissions, viz. SOx, etc. EGR has also been used in some works and was found to be effective. The Thermal converters and catalytic converters are devices that are used to control the harmful emission after they have been generated in the engine. Compared to thermal converters, catalytic converters are used very widely used. The use of bio-diesel has also been found to reduce the emissions from diesel engines.

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