Energy and Environment: Challenges and Strategies; in context to Automobiles

Shailendra Sinha[*1]

ABSTRACT

Development of any country mainly depends on availability of energy, at the same time most of the environmental problems are associated with the use of energy. Sustainable development should be approached in all of its primary dimensions: economic, environmental and social. Energy has deep and broad relationships with each of the three pillars of sustainable development. Rapid industrialization, increasing urbanization and motorization and increase in consumption of fossil fuels are main reasons for environmental degradation. Emissions associated with combustion of fuel have a significant impact on the ecosystem, affecting animals, plants and aquatic life. Transport sector is one of the major contributors to pollution in urban areas. If present trends continue, including the heavy reliance on fossil fuels, risks will build up not only in the environmental dimension but also in the economic dimension. We need to change not only the structure of the energy sector but also behavior in our societies and economies. This paper reviews the use of biofuels, pollutant formation from engines and methods to control emissions for cleaner environment and sustainable development.

Keywords : *Biofuel, Fuel Regulation, Emission Standards, Hydrocarbons, Fuel Modification.*

1. INTRODUCTION

An ideal environment is one, which has fresh air, pure water and noise-free surroundings. The increasing industrialization of the world has led to a steep rise in demand for energy specially the fossil fuels. By now, it has been realized that the internal combustion engines form an indispensable part for industrial growth as well as for modern agricultural activities. It is impossible to do away with IC engines at this juncture and alternative fuel must be sought to ensure safe survival of the existing engines. Identification of appropriate alternatives to the conventional fuels has been subjected to a variety of technical, political, geographical and economic considerations. Transport sector is one of the major contributors to pollution in urban areas. For vehicular pollution, emissions standards like US EPA norms in USA, EURO standards in European countries have been enforced. Since the year 2000, India also started adopting European emission and fuel regulations for four-wheeled light-duty and for heavy-duty vehicles (Bharat norms). Standards generally regulate the emissions of NO_x, particulate matter (PM) or soot, carbon monoxide (CO), or volatile hydrocarbons. The main components of automobile exhaust, carbon dioxide (CO_2) and water vapor (H_2O) have so far not been regulated by emission standards, but the European Union is moving towards mandatory CO_2 limits in near future. Kyoto protocol has emphasized on green house gases (GHGs) reductions in the atmosphere. CO_2 is the main gas responsible for green house effect. Atmospheric concentration of CO_2 has grown from 316 parts per million by volume (ppmv) in 1959 to 360 ppmv in 1996 and nearly 400 ppmv in 2013. The major culprit for CO_2 increase is power plant and transportation sector, responsible for 2/3rd of total CO_2 increase in the atmosphere. The projected trends in energy use imply that global energy-related CO_2 will rise to a level of 600 ppmv

1*. Shailendra Sinha, Institute of Engineering & Technology, Sitapur Road, Lucknow.

by 2050, which will result in a projected increase in global temperature by 3°C [1]. This increasing level of GHGs could be curtailed by enhancing energy efficiency and through replacement of petroleum fuel by bio-fuels.

The diesel engine is a major tool in the day-to-day life of modern society. It powers much of our land and sea transport, provides electrical power, and is used for many farming, construction, and industrial activities and their use will continue and grow into the future. Large emission reductions may be achieved through fuel reformulation, engine redesign, and exhaust treatment. Utilization of renewable energy is a basic need for the overall sustainable development.In the long term, fossil-fueled transportation systems may be replaced by renewable sources of energies and biofuel. This review summarizes and evaluates published information on pollutant formation, their effects and techniques to reduce emissions.

2. MECHANISM OF FORMATION OF POLLUTANTS

The exhaust gas emitted by engines is a complex mixture, which contains more than several hundred different organic and inorganic particulates and gaseous compounds [2-4]. The pollutants from internal combustion engines mainly include un-burnt hydrocarbons (UBHC), carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), particulates (PM) etc. These pollutants have serious effects on human health as well as ecological system. Pollutants are emitted from automobile by three main sources:

- The crankcase; from where piston blow-by gases and oil mist are vented to the atmosphere.
- The fuel system; from where evaporative emissions leaks to the atmosphere.
- The exhaust system; from where the products of combustion are expelled into the atmosphere.

2.1 Carbon Monoxide

Carbon monoxide is primarily dependent on the availability or lack of oxygen i.e., air-fuel ratio. In the rich air fuel ratio operation there is not enough oxygen to oxidize C atoms completely to CO_2 and partial oxidation of C leads to formation and emission of CO.

In SI Engines, the presence of CO for the air fuel ratios higher than stoichiometric is the result of :

(i) Dissociation reactions in the exhaust gases
(ii) Mixture may not be entirely homogeneous and can result in local rich mixture generating CO
(iii) Freezing of oxidation reactions as excess air is available or reactions occurring near walls

In CI Engines, local extremely rich mixture zones exist due to heterogeneous mixture of fuel and air. Emission of CO depends upon the extent of post-oxidation reactions and freezing of oxidation reactions. Some CO is formed in the over lean regions (LFOR) of spray due to slow oxidation reactions.

2.2 Nitrogen Oxides

Nitrogen oxides largely consist of nitric oxide (NO) and a small amount of nitrogen dioxide (NO_2). These are primarily formed by the oxidation of atmospheric oxygen in the combustion chamber. Principal reactions governing formation of NO are given by the extended Zeldovich mechanism as below;

$O + N2 \Leftrightarrow NO + N$; $N + O2 \Leftrightarrow NO + O$; $N + OH \Leftrightarrow NO + H$

These reactions become significant at high temperatures. The combustion temperatures (adiabatic flame temperature) and the availability of oxygen govern NO formation.

2.3 Unburned Hydrocarbons

In SI Engines Hydrocarbons remain unburned in the combustion chamber due to

S-JPSET : ISSN : 2229-7111, Vol. 5, (Special Edition-I)

- Flame quenching at the relatively colder combustion chamber walls
- Unburned mixture filling the crevices regions
- Partial or complete engine misfiring during engine transients
- Absorption of fuel vapors into oil film on the cylinder wall during intake and compression strokes and desorption during expansion and exhaust strokes.

  In the diesel engines, two main sources of HC emissions are;

(i) Overleaning: Some of the fuel injected during ignition delay period may have mixed to produce mixture beyond lean flammable limits. Increase in ignition delay has been seen to increase HC emissions.

(ii) Undermixing: Fuel that leaves the injector nozzle at low velocity late in the combustion process i.e., the fuel coming out of nozzle sac volume will have little time to mix with air and may escape combustion process. Quenching of combustion and misfire under cold conditions also increases HC Emissions.

2.4 Diesel Particulates

Diesel particulate matter is part of a complex mixture that makes up diesel exhaust. It consists of combustion generated carbonaceous matters (soot) on which fuel and lubricating oil derived heavy hydrocarbons are absorbed. In addition sulphates, water and other in-organic matter may also be adsorbed on the basic soot particles as shown in figure1.

Typical composition of PM

C	**31%**
Sulphate & H_2O	**14%**
Unburned fuel	**7%**
Unburned Oil	**40%**

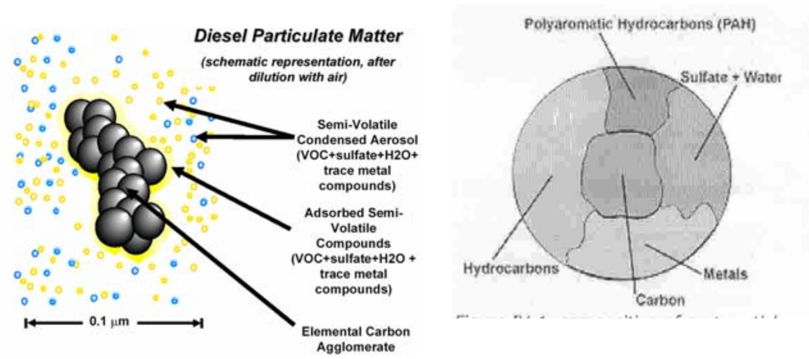

Fig.1. The Nature of Particulate Matter

3. POLLUTION CONTROL STRATEGIES

Reducing the pollution that comes from vehicles will usually require a comprehensive strategy that includes four key components: emissions standards for new vehicles, specifications for clean fuels, programs to assure proper maintenance of in-use vehicles, and transportation planning and demand management. Emission by the vehicles may be controlled by following strategies.

- Fuel modification
- Modification in engine (In-cylinder control) i.e. Air handling, Fuel handling, Electronic control etc.
- Exhaust after treatment devices like catalytic converter, DOC, DPF, EGR, SCR etc)

3.1 *Fuel Modification*

Over the course of the past 30 years, pollution control experts around the world have come to realize that cleaner fuels must be a critical component of an effective clean air strategy. In recent years, this

 S-JPSET : ISSN : 2229-7111, Vol. 5 (Special Edition-I)

understanding has grown and deepened and spread to most regions of the world. Diesel fuel improvements have resulted in large reductions of SO_2 and PM emissions. Fuel changes, such as reduced sulfur and aromatics content resulted in significant reduction Particulate matter (PM) formation [7]. Fuel sulfur content affects engine wear, deposit formation, emissions and also reduce the effectiveness of emission control equipment, especially the efficiency of catalysts. Cetane number improvement results in better combustion. The cetane number increases through the use of ignition improvement additives, such as 2-ethyl hexyl nitrate etc. In the case of Euro 3 and Euro 4 vehicle emission standards, even lower sulphur levels (350 ppm and 50 ppm, respectively) in diesel fuel will be required to ensure compliance with the standards. Diesel fuel has natural lubricity properties from compounds including the heavier hydrocarbons and organo-sulfur. Refining processes to remove sulphur and aromatics from diesel fuel tend to reduce the natural lubricity of diesel**.** Additives are available to improve lubricity and should be used with fuels with 50 ppm sulfur or less**.** This reduced lubricity can also be counteracted by blending in a very high lubricity biodiesel.

Improving energy security, reducing vehicular contributions to air pollution and reducing/eliminating greenhouse gas emissions are primary goals compelling governments to identify and commercialize alternatives to the petroleum fuels. Alternative fuels like hydrogen, CNG, ethanol and biodiesel, electric and hybrid vehicles etc may be used. Ideally, alternative fuels should be easily available, environment friendly and techno-economically competitive. Synthetic diesel fuel, with nearly zero sulfur and aromatic contents, is the cleanest burning of the reformulated diesel fuels. The fuel is produced by the gas-to-liquid chemical conversion process known as Fischer Tropsch (FT). Microemulsions of water or ethanol in diesel fuel have been shown to reduce both PM and NOx emissions through rapid vaporization of the emulsified droplets.

Biodiesel is fatty acid ethyl or methyl ester made from (new or used) vegetable oils (edible or non-edible) and animal fats. The use of biodiesel in conventional diesel engines results in substantial reduction of unburnt hydrocarbons, carbon monoxide and particulate matter emissions [5].

3.2 Engine Modification and Future Engine Technology

Existing emission standards may be met by modifying the engine and through the use of after treatment devices that remove pollutants from the engine exhaust. Gasoline-fuelled passenger cars relied on reformulated fuel (unleaded gasoline) and after treatment devices (catalytic converters) to reduce emissions for many years. Fuel injection rate shaping, exhaust gas recirculation (EGR), and advanced combustion techniques can provide additional emissions reductions [6]. Following engine modification and technologies may help to reduce engine emissions.

- Combustion optimization-4v, CC, air motion
- Higher injection Pressures-CR, UI
- Retarded injection timing, Electronic control of injection
- Exhaust Gas recirculation
- Turbocharging
- GDI, HCCI,
- Hybrid vehicle, electric vehicles and air engines

Diesel engine emissions Control techniques are usually limited by a NOx and PM tradeoff, where strategies to reduce one pollutant may result in an increase to the other. Injection timing retard reduces the peak flame temperature, resulting in NOx reductions. However, timing retard typically results in lowers fuel efficiency and higher PM emissions. High pressure fuel injection can regain some of the efficiency loss by improving the atomization of the fuel spray and air utilization, resulting in more complete combustion [6]. Injection rate shaping (possible due to electronic control and re-engineering of the fuel injectors) tailors the fuel injection event to reduce peak flame temperatures without increasing fuel consumption. Injection rate shaping has been shown to simultaneously reduce NOx and PM under certain operating conditions [6].

Diesel emissions are reduced by turbocharging, aftercooling, optimizing combustion chamber design, retarding injection timing, and high-pressure fuel injection [6]. After cooled turbochargers reduce both NOx and PM emissions by ~33%, compared with naturally aspirated engines [7].

Modifications to the shape of the combustion chamber, location of the injection swirl, crevice volumes, and compression ratios also optimize fuel efficiency and pollutant reductions. Improved in-cylinder flow management, such as the design of the intake port and valve and increased swirl for better combustion may be achieved via optical diagnostic techniques and computational models [8,9,].

EGR is a most effective technique for reducing NO_x formation in the combustion chamber. It reduces NOx formation in the combustion chamber by diluting the air with inert exhaust gas that reduces peak flame temperatures when fuel is ignited. This also reduces the O_2 concentration in the combustion chamber [10].

Conventional diesel engines NOx formation is high on the lean side of the flame, and PM formation is high on the rich side of the flame. In homogeneous charge compression ignition (HCCI) systems, fuel and air are premixed prior to introduction into the combustion chamber. Ignition occurs spontaneously throughout the mixture as a result of compression. This process produces ignition at a large number of sites throughout the combustion chamber, eliminating locally lean and rich zones that cause high NOx and PM [11].

Now a days research has been underway to develop an unthrottled, stratified charge, direct injection SI engine to reap theoretical fuel efficiency and emission advantages of this concept. Introduction of electronically controlled valve gear operation to improve engine air breathing and impart desired air motion in the cylinder, and electronic fuel injection to obtain desired air - fuel mixture formation and composition have made GDI engine a reality resulting in significant improvements in performance and emissions.

Another alternative on the horizon is the hybrid electric Vehicle (HEV) system, which uses an electric drive, typically with a diesel internal combustion engine and a traction battery. Hybrids yield lower NOx and PM emissions and higher fuel economy. The prime mover of HEV operates at steady load speed conditions at the optimum efficiency point and energy storage devices like batteries take care of transient operation needs of the vehicle. Supplementing power of the IC engine with the electric motor can downsize engine.

Electrochemical battery powered vehicle (EV) is cleanest of all, but the batteries are slow to recharge, and have limited range and power density for acceptable automotive propulsion. Fuel cells are preferred to batteries as it can generate electricity on board from hydrogen for propulsion of an electric vehicle. Fuel cells have the potential to replace diesel engines in truck, bus, and certain off-road applications. In transportation applications, hydrogen can be carried on-board, reformed from methanol using a low-temperature reformer or reformed from higher HC fuels using high-temperature reformers.

3.3 Exhaust after treatment

When the first emission controls were first introduced back in the late 1960s, they were primarily "add-on" components that solved a particular emission need. Positive crankcase ventilation (PCV) became standard in 1968 to reduce blow by emissions. In 1971, charcoal canisters and sealed fuel systems were added to control evaporative emissions. But the most significant add-on came in 1975 when the auto makers were required to install catalytic converters on all new cars. The early "two-way" converters (to control HC and CO) acted like an afterburner to reburn the pollutants in the exhaust. In 1981 "three-way" converters were introduced. Three-way converters also reduced NOX concentrations in the exhaust, but required the addition of a computerized feedback fuel control system to do so. To reduce all three pollutants (HC, CO and NOx), a three-way converter requires a fuel mixture that constantly changes or flip flops back and forth from rich to lean. This, in turn, requires feedback carburetion or electronic fuel injection, plus an oxygen sensor in the exhaust to keep tabs on what's happening with the fuel mixture.

As combustion system refinements and EGR reach their limits, NOx and PM after treatment devices will be needed to comply with increasingly stringent emission standards. NOx aftertreatment devices include the lean NOx catalyst, the NOx adsorber, and selective catalytic reduction (SCR) while particulate matter emission may be taken care of by Diesel Particulate Filters (DPFs).

Lean NOx catalysts have been shown to provide up to 30% NOx reduction under certain operating conditions although fuel efficiency is reduced by 7%. NOx adsorbers operate by storing NOx under typical diesel engine operations ("lean" conditions). Before the NOx adsorbent becomes fully saturated, engine operating conditions and fueling rates are adjusted to produce a fuel-rich exhaust that reduces the stored NOx to nitrogen. Under these rich conditions, the stored NOx is released from the adsorbent and simultaneously reduced to N_2 over precious metal adsorber catalyst sites. An engine management system is critical to the operation of the NOx adsorber system. The concern with fuel sulfur is that sulfur dioxide (SO_2) formed can deactivate the active catalyst sites and make the adsorbers less efficient over time. Improved NOx adsorber desulfurization systems, sulfur-resistant active catalyst layers, and other methods are under development to maintain the NOx adsorber's high efficiency for the useful life of the engine.

Selective Catalytic Reduction (SCR) is the most effective method of controlling nitrogen oxide emissions (NOx) from combustion sources. It is a commercially proven flue gas treatment technology that has been demonstrated to remove over 90 percent of the NOx contained in combustion system exhaust gas. In the traditional SCR systems, NOx (mainly NO) is reduced by ammonia to form nitrogen and water. The catalyst is at the heart of the SCR process. It creates a surface for reacting the NOx and ammonia, and allows for the reaction to occur within typical flue gas temperature ranges. The active ingredient in most NOx catalyst is Vanadium Pentoxide (V_2O_5). For higher temperatures zeolites, tungsten or titanium matrices may be utilized as well. Ammonia acts as reducing agent and is injected upstream of the catalyst. On the surface of the catalyst, the NOx will be selectively reduced by reacting with the ammonia in the presence of oxygen to form harmless byproducts, water and nitrogen (H_2O & N_2**).** Urea would probably be used to provide the reactant. The main challenges for SCR are controlling the rate of urea introduced to maximize NOx reductions without "ammonia slip" through the catalyst and ensuring that the urea is properly replenished throughout the vehicle life to ensure emission reductions.

Diesel Particulate filters (DPF) are placed in the exhaust flow to reduce the amount of particulates released to the atmosphere. Filters are often made of ceramic in the form of a monolith or mat, or else made of metal wire mesh. Filters typically remove 60–90% of particulates in the exhaust flow. As filters catch the soot particles, they slowly fill up with the particulates and need to be regenerated. Regeneration consists of combusting the particulates in the excess oxygen contained in the exhaust of the lean-operating CI engine. Many techniques like Fuel-borne Catalysts, in cylinder post injection of fuel, Electricity aided Regeneration, microwaves can and are being used to regenerate a diesel particulate filter, both on- and off-board.

4. CONCLUSIONS

Engine technology has improved substantially in recent years. However, in parallel with the technological advancement the need of the day is further reducing the emissions. Pollutants from the engines adversely affect all aspects of the natural environment—land, water, and air. Diesel PM has been associated with lung cancer and short-term respiratory ailments, such as asthma, in occupational and general population epidemiologic studies. Tumors and cell damage have been found in animals exposed to high DPM concentrations, although these concentrations are typically much larger than those found in normal atmospheres. Small particles, which are both directly emitted from diesel engines and formed from gaseous emissions, can lead to premature death and major respiratory problems.

Significant progress has been made in reducing engine emissions through improved engine design and fuel reformulation. These advances have often improved fuel economy, thereby offsetting some of the costs of new technology. Since 1980, up to 90% reductions in DPM and NOx emissions have been achieved with fuel injection rate shaping and combustion system refinements.It is expected that high-efficiency after treatment devices like SCR, DPF etc will effectively reduce emissions. Another promising new heavy-duty technology being demonstrated is a hybrid-electric engine system that can reduce DPM and NOx emissions by 25% or more, compared with the current diesel engine.

REFERENCES

[1] Anon, petroleum statistics, Ministry of oil & natural gas, Government of India, http://www.peroleum.nic.in/petsteat.pdf.

[2] Kagawa, J., Health effects of diesel exhaust emissions mixture of air pollutants of worldwide concern, Toxicology 181-182, 2002, pp 349-53.

[3] Sher, E., Handbook of Air Pollution from Internal Combustion Engines, academic Press, USA.

[4] Lloyd, A.C., Cackette, T.A., Diesel Engines: Environmental Impact and Control, Journal of Air & Waste Management Association, Vol. 51, 2001, pp. 809-47.

[5] Krawczyk, T., Biodiesel–Alternative fuel makes inroads but hurdle remains, INFORM 7,1996,pp801-15

[6] Alan C. Lloyd and Thomas A. Cackette, Diesel Engines: Environmental Impact and Control, California Air Resources Board, Sacramento, California

[7] Monaghan, M.L. Particulates and the Diesel-The Scale of the Problem; *IMechE* ,**1998**, pp vii-xv.

[8] Dec, J.E. Conceptual Model of DI Diesel Combustion Based onLaser-Sheet Imaging. SAE 1997 World Congress, Societyof Automotive Engineers, Warrendale, PA, 1997; Paper No.970873.

[9] Dec, J.E.; Canaan, R.E. PLIF Imaging of NOx Formation in a DI Diesel Engine. SAE 1998 World Congress, Society of Automotive Engineers, Warrendale, PA, 1998; Paper No. 980147.

[10] Pierpont, D.A., Montgomery, D.T., and Reitz, R.D., 1995, "Reducing Particulate and NOx Using Multiple Injections and EGR in a D. I. Diesel", SAE, 950217.

[11] Gray, A.W., III; Ryan, T.W., III. Homogeneous Charge Compression Ignition (HCCI) of Diesel Fuel. SAE 1997 World Congress, Society of Automotive Engineers, Warrendale, PA, 1997; Paper No. 971676.

