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The effect of vehicular pollution on environment and sustainable alternative solutions

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Abstract

Air pollution is one of the serious environmental concerns globally and particularly Asian cities including India where majority of the population is exposed to poor air quality. The health related problems such as respiratory diseases, risk of developing cancers and other serious ailments etc. due to poor air quality are known and well documented. Most of the Cities are also experiencing rapid urbanization and majority of the country's population is expected to be living in cities within a span of next two decades. The rapid urbanization has also resulted in a tremendous increase the number of motor vehicles. The vehicle fleets have even doubled in some cities in the last one decade. As the number of vehicles continues to grow and the consequent congestion increases, vehicles are now becoming the main source of air pollution in urban area, however taken a number of measures for the improvement of the air quality. These include, right from the improvement in the fuel quality, formulation of necessary legislation and enforcement of vehicle emission standards, improved traffic planning and management etc. The non-technical measures taken include, awareness raising regarding the possible economic and health impacts of air pollution. The available technical measures for improving air quality, increasing use of cleaner fuels and purchase of vehicles with advance emission control devices, increasing institutional framework and capacity building for the monitoring of vehicle emissions. The paper presents a review of the vehicular emission problems in Indian cities and the various sustainable technological developments are being introduced with more emphasize on thermal impact on automotive engines after needful research work.

Keywords: Vehicular emissions; pollutants; emission control; air pollution; alternative fuels; automotive engines.

1. Introduction

The air quality can be improved through a combination of technical and non-technical measures, legislative reforms and institutional approaches, there are certain unique challenges which the country has to face in tackling the problem of urban air pollution. These include, the transport features which are different from the developed countries particularly the types of vehicles commonly used, the road network is operated and sharing of the limited space by pedestrians and non-motorized modes with modern vehicles in Indian cities. The country has however taken a number of measures for the improvement of the air quality in cities. These include improvement in the fuel quality, formulation of necessary legislation and enforcement of vehicle emission standards, improved traffic planning and management etc. The paper presents the vehicular emission problems in Indian cities, the various developments took place including the latest technologies, the steps taken for improvement in the quality of the automotive fuel, engine design, alternative fuels, improved alternative technologies, the overall impact of these measures and the future strategy to be adopted for vehicular emission reduction and related issues. [2,3,6]

2. Major Vehicle - Fuel Pollutants

The major sources of air pollution are the flue gases, emission from refineries and factories, etc., on one hand; and exhaust emissions from vehicles on the other hand. The diesel fumes are more carcinogenic. Euro III diesel cars emit 7.5 times more toxic particulate matter (PM) than comparable petrol cars. Apparently, many efforts are needed to arouse awareness among the consumers to reduce emissions by means of new and innovative automobile technologies and alternative fuels. [2,5]

Automotive vehicles emit several pollutants depending upon the type of quality of the fuel consumed by them. The release of pollutants from vehicles also include fugitive emissions of the fuel, the source and level of these emissions depending upon the vehicle type, its maintenance etc. The major pollutants released as vehicle/fuel emissions are, carbon monoxide, nitrogen oxides, photochemical oxidants, air toxics namely benzene, aldehydes, 1-3 butadiene, lead, particulate matter, hydrocarbon, oxides of sulphur and polycyclic aromatic hydrocarbons. While the predominant pollutants in petrol/gasoline driven vehicles are hydrocarbons

and carbon monoxide, the predominant pollutants from the diesel based vehicles are Oxides of nitrogen and particulates. A detail on emissions emitted by vehicles is given in table 1. [4,5]

Table 1: A detail on emissions emitted by vehicles [9]

Categories	CO_2	CO	NO_x	CH_4	SO_2	PM	HC
Bus	28748.16	207.26	679.73	5.02	79.24	31.36	51.72
Two wheelers	8701.08	719.64	62.15	58.88	4.25	16.36	464.49
Cars and jeeps	23901.22	212.30	22.14	18.17	5.67	3.22	28.01
Trucks and lorries	70288.92	491.15	859.51	12.28	193.73	38.20	118.69
Light motor vehicles	44654.58	442.04	110.94	7.80	123.08	17.33	12.13
Trailers and tractors	46563.85	460.94	115.69	8.13	128.34	18.08	12.65

Pollutants in Gasoline Vehicles Emissions primarily consisting of CO, HC, oxides of nitrogen (NOx), SO_2, and partial oxides of aldehydes, besides particulate matters including Pb salts account for the larger chunk of all pollution from gasoline-run vehicles. Pollutants in Diesel vehicles Emissions as diesel engines breathe only air, blow by gases from the crankcase are rather low. Moreover, due to its low volatility, evaporative emissions from the fuel tank can safely be ignored. Though the concentration of CO and un-burnt HC in the diesel exhaust are rather low, they are compensated by high concentration of NOx (higher than that in gasoline vehicles). There are smoke particles and oxygenated HC, including aldehydes and odour-producing compounds which have high nuisance value. Smoke from diesel engines comes in three different hues – white smoke emitted during cold start idling and at low loads; blue smoke from the burning of lubricating oil and additives; and black smoke, a product of incomplete combustion. Black smoke, the most obvious type of vehicular air pollution, consists of irregular shaped agglomerated fine soot/particulates, the formation of which depends on injector nozzle parameter and type of combustion chamber (direct or indirect injection).[2,3]

2.1 Various Emissions Emitted by Vehicles

Pollution from vehicles especially automobiles is responsible for about two third of air pollution in the urban area. Main sources of emission from automobiles are as described below; [2,5,6]

2.1.1 Crankcase Emission

Crankcase Emission (also called running loss emissions) is unburnt or partially burned fuel components that, under pressure, escape from the combustion chamber, pass the pistons and enter the crankcase. This mixture is called blow-by.

2.1.2 Evaporative Emissions

Evaporative Emissions HC vapours, lost constantly and directly to the atmosphere due to volatile nature of petrol, mainly from the fuel line's, fuel tank and carburettor depending upon fuel composition, engine operating temperature and ambient temperature.

2.1.3 Exhaust Emission

Automotive exhaust is the major source constituting about 60% of the total emission. Automobile exhaust consists of (1) Hydrocarbons (Unburnt), (2) Carbon monoxide, (3) Oxides of nitrogen (NOx), (4) Lead oxides, (5) Particulate matters e.g. lead, carbon, alkaline earth compounds, iron oxide, tar, oil, mist (6) Traces of aldehydes, esters, ethers, sulphur dioxide, peroxides, ketones benzene (C6H6), 1, 3 butadiene, Poly Aromatic Hydrocarbons (PAH), metal dust, asbestos fibre, dioxin, furon, ammonia, organic acids , chlorofluorocarbons (CFCs) etc. The major pollutants emitted from exhaust emissions of gasoline fueled vehicles are CO, HC, and NOx ,while pollutants from diesel-fueled vehicles are particulate matter (including smoke), NO_X, SO_2, PAH. More information of these pollutants is as given below.

- **Carbon Monoxide (CO)** - colourless and odourless gases slightly denser than air. Residence time and turbulence in the combustion chamber, flame temperature and excess O_2 affect CO formation. Conversion of CO to CO_2 in the atmosphere is slow and takes 2 to 5 months.
- **Hydrocarbon Compounds (HC)** - Compounds consist of carbon and hydrogen and include a variety of other volatile organic compounds (VOCs). Most HCs are not directly harmful to health at concentrations found in the ambient air. Through chemical reactions in the troposphere, they play an important role in forming NO_2 and O_3 which are health and environmental hazards.
- **Benzene and Polyaromatic Hydrocarbons (PAH)** - Motor vehicles emit toxic HC including benzene, aldehydes and Polyaromatic hydrocarbons (PAH).
- **Nitrogen oxides (NO_X)** - includes nitric oxide (NO), nitrous oxide (N_2O), nitrogen dioxide (NO_2), dinitrogen trioxide (N_2O_3) and nitrogen pent oxide (N2O5). NO and NO2 collectively represented as NO_X, are the main nitrogen oxides emitted by vehicles.
- **Sulphur dioxide (SO_2)** - is a stable, non-flammable, non-explosive, colourless gas. In the atmosphere, SO_X may be converted to sulphur trioxide (SO_3) by means of reaction with

O_2. SO_2 and SO_3 react with moisture in air to form sulphurous (H_2SO_3) and sulphuric (H_2SO_4) acids may precipitate to earth as acid rain.

- **Ozone (O_3) -** in the lower (troposphere) layer, ground level ozone (GLO) is formed by the reaction of VOCs and NO_X with ambient O_2 in the presence of sunlight and high temperatures.
- **Particulate matter (PM) -** consists of fine solids and liquid droplets other than pure water dispersed in air. Total suspended particulates are particles with an aerodynamic diameter greater than 70 µm. PM with an aerodynamic diameter greater than 10 µm known as suspended inhalable particulate matter/Respirable Suspended Particulate Matter (RSPM) or PM10.
- **Black smoke**, associated with the soot portion of PM emitted by diesel-fuelled vehicles, results from the deficiency of O_2 during the full combustion or expansion phase. Blue, grey and white smokes are caused by the condensed HC in the exhaust of diesel-fueled vehicles.
- **Dioxins-** Cu based additives can reduce PM emissions but may catalyze the reaction between HC and trace amounts of chlorides in diesel fuel to form dioxins which are emitted in the exhaust.
- **Chlorofluorocarbons (CFCs) -** The source of CFC emissions from motor vehicles is the Freon gases used in air conditioners. CFC emitted into the atmosphere rise to the stratosphere layer within 10 years and is estimated to remain there for 400 years.
- **Carbon dioxide (CO_2) -** is a green house gas associated with global warming, resulting mainly from increased combustion of fossil fuels including motor vehicle fuels. [2,5]

3. Pollution Hazards and Human Health

The major pollutants emitted by motor vehicles including CO, NOx, sulphur oxides, (SO), HC, lead (Pb) and suspended particulate matter (SPM), have damaging effects on both human health and ecology. The human health effects of air pollution vary in the degree of severity, covering a range of minor effects to serious illness, as well as premature death in certain cases. Most of the conventional air pollutants are believed to directly affect the respiratory and cardio-vascular systems. In particular, high levels of SO2 and SPM are associated with increased mortality, morbidity and impaired pulmonary function. Lead prevents hemoglobin synthesis in red blood cells in bone marrow, impairs liver and kidney function and causes neurological damage. [3,6]

(i) Carbon monoxide (CO): The affinity of blood hemoglobin is 200 times greater for carbon monoxide than for oxygen, CO hinders oxygen transport from the blood into the tissues. The low level of exposure accelerate and angina (chest pain) in people having coronary artery diseases.

(ii) Nitrogen Oxides Nitrogen dioxide (NO_2): It has been linked with increased susceptibility to respiratory infection, increased airway resistance in asthmatics, and decreased pulmonary function.

(iii) Photochemical Oxides (Ozone O_3): The pollutants release from vehicles also results into formation of ozone through chemical reactions. The ground level ozone which is the main part of the smoke can cause respiratory problems such as chest pain, cuffing etc.

(iv)Oxides of Sulphur (SO_2): High concentrations of sulfur dioxide (SO_2) can result in temporary breathing impairment for asthmatic children and adults who are active outdoors.

(v) Gaseous Air Toxins: The toxic air pollutants that may have a significant effect on public health. Benzene is a known human carcinogen by all routes of exposure.

(vi) Lead: affects many organs and organ systems in the human body, with sub-cellular changes and neurodevelopment effects appearing to be the most sensitive.

(vii) Particulate matter (PM): The key health effects associated with PM include premature death; aggravation of respiratory and cardiovascular disease.[3,6]

4. Discussion- Alternative Solutions [5,6,9]

- Reduction in usage of automotive independently
- Adoption of public transport
- Cycling
- Retrofitting of new technology in existing automotives
- Usage of alternative fuels
- Use of innovative technologies
- Use of hybrid vehicles
- Use of electric vehicles etc.

The new and innovative technologies related to automobiles being in consideration are as follows.

4.1 Role of Innovative Technologies

4.1.1 Crank Case Emission

Crank case emissions can be minimized by providing positive crank case reventilation (Positive Ventilation system). Emission from the exhaust can be controlled by a combination of methods like,

- Exhaust gas re-circulation for control of the oxide of Nitrogen,
- Catalytic or non-catalytic conversion of hydrocarbons
- Oxidation of carbon monoxide and unburnt hydrocarbons in the exhaust system by low pressure air injection into the exhaust port.
- Engine modification to reduce the volume of contaminants released from the cylinders.

4.1.2 Evaporative Emission

Emission of fuel vapour from carburetor and fuel tank may be reduced by installing fuel vapour recovery systems. The vapour-return line which connects the fuel pump to the fuel tank, allows the vapour formed in the fuel pump to return to the fuel tank. At the same time, it permits excess fuel pumped by the fuel pump to return to the fuel tank. In some

cars, a vapour separator is connected between the fuel pump and the carburetor. The vapour formed in the fuel pump enters the vapour separator, as bubbles, along with the fuel. The vapour rises to the top of the vapour separator, from which it is forced due to the fuel pump pressure, to pass through the vapour returning line to the fuel tank.

4.1.3 Exhaust Emissions

There are several methods to control the oxides of nitrogen (NO2) present in the IC engine exhaust. Basically, there are two ways,

- By controlling the formation of NOx itself through changing the operating or design parameters or by some device to reduce the peak combustion temperature mainly responsible for the formation of NOx in the combustion chamber and
- By using a catalyst in the exhaust system to reduce NOx to nitrogen and oxygen after its formation.

The other possible methods to control NOx emissions at the sources are

- Recirculation of the part of the exhaust gas
- Water injection into the inlet manifold.
- Charge dilution with some gas like carbon-dioxide, helium, argon, etc.

4.1.4 Exhaust Gas Recycling (EGR)

It is proved from the experiments that EGR is a promising method to control NOx emission. EGR controlled 81-88% of NOx at 30% recycling.

- With 30% recycling, there is a fuel penalty of 23.1% to 28% considered to minimize *bsfc* value increased from 3.85% to 28% when the percentage recycling increased from 10% to 30%.
- With 30% recycling, as the speed increased from 1200 rpm to 1800 rpm, the loss is maximum power output increasing from 9% to 13.5% and from 1.88% to 13.5% in the recycling range of 10% to 30%. Even with 20% recycling, the loss is maximum and power is high as 31.8% with running at 2400 rpm.
- The rate of reduction of NOx emission is much faster at higher speeds with increase in percent recycling.
- The peak exhaust temperature increases with the rise in percent recycling as well as speed.
- Exhaust gas recycling helps in the reduction of carbon monoxide emission as well.

4.1.5 Fuel factors

These are Cetane Number, Volatility, Viscosity and Chemical Composition. Considerable success has been achieved in recent years on diesel smoke problems by means of fuel additives; of which certain additives containing barium effectively reduce the exhaust smoke density.

4.1.6 Engine Design

The type of combustion system is the most important engine design features, which affects exhaust smoke density. An indirect injection engine releases less smoke than a direct injection engine for large part of the operating range of loads, due to high rate of air swirl resulting in better air utilization. [5,6,9,12]

4.1.7 Engine Précising cooling system

Temperature control is very important for combustion engines as temperature is a critical factor both for chemical reactions and mechanical stresses. Traditionally, temperature control is performed by feedback of the coolant temperature, which however is a poor indicator of specific temperatures. Engine Systems can be optimized & evolved to provide precision cooling with necessary changes in Engine operational settings, to reduce excessive heating & irregular temperature gradient across the engine. In the present scenario the designs of engine being used in automotives by various manufacturers are not properly suitable to tropical countries climatic condition. In these countries variation in the ambient temperature ranges from 0^{oC} to 50^{oC} in different regions. Looking in to this vast varying temperature rang analysis conducted on various fuels that which temperature is most suited to operating condition of engines and gives best performance levels for fuel consumption and emission is concerned. Presented in figures 1 below; [10]

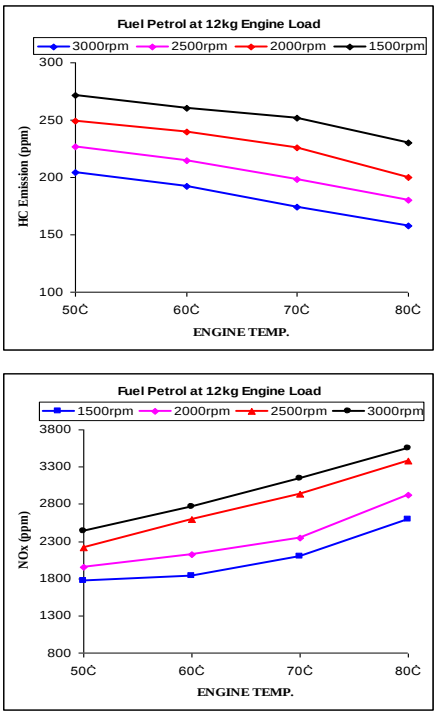


Fig. 1 Effect of engine operating temperature on emissions (SI engine)

4.1.8 Effect of Engine life and maintenance

The condition of the fuel injection systemhas the greatest influence on exhaust smoke density. To perform the functions of engine satisfactorily throughout the engine service life, all the components of the fuel system must be in good mechanical condition and must be correctly assembled and tuned. As the wear of these components with increasing use is inevitable, and as deposit build up takes place on some of the critical components, periodic maintenance is essential to keep the smoke level low.

4.2 Use of Alternative Power Source

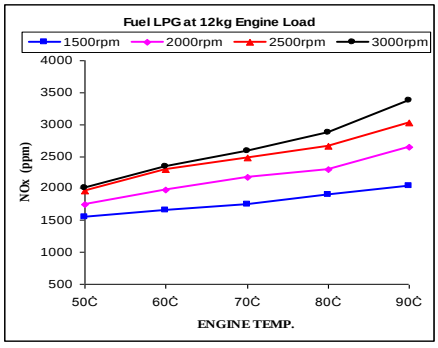
The vehicular pollution can be reduced by the use of alternative fuels, which is given as below.

- LPG, CNG etc
- Bio-Diesel Blends, bio-fuels
- Battery operated
- Hydrogen
- Solar operated

4.2.1 LPG

Liquefied Petroleum Gas is mixture of gases, chiefly propane and butane, produced commercially from petroleum and stored under pressure to be kept in a liquid state. The LPG is an attractive fuel for internal combustion engines; because it burns with little air pollution and little solid residue, besides that, it does not dilute lubricants, and it has a high octane rating. The research experience in this area indicates that there is 90% reduction in toxic emissions as compared to reformulated gasoline, in addition, it also reduces the HC and CO_2 22-24% approx as compared to gasoline.

The effect of engine temperature (Fig.2) plays an important role on emissions particularly when it runs on LPG. [5,10]



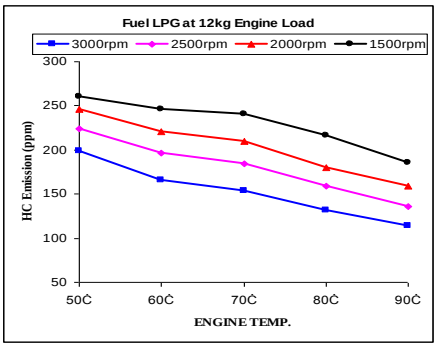


Fig. 2 Effect of engine operating temperature on emissions (LPG retrofit SI engine)

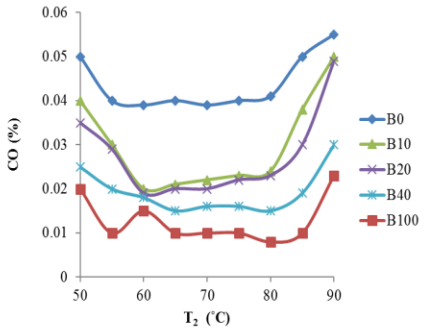
4.2.2 CNG

Compressed Natural Gas is composed of Methane, Ethane, Propane, Butane and other contaminants. The main constituent of CNG is Methane which will be up to minimum of 90%. Due to its low energy density, it is compressed to a pressure of 200-250 kg/cm^2 and the name is Compressed Natural Gas. It also reduces CO to 97%, HC to 20 to 25% as compared to gasoline fuel.

4.2.3 Bio-Diesel Blends

Bio-fuels can be good alternative for diesel for most of developing countries. Among all alternatives being considered are ethanol, methanol, biogas and vegetable oil. Bio-diesel is one such promising fuel for compression ignition engines, which has characteristics very close to diesel. Bio-diesel can be used in diesel engine without engine modifications. There are more than 300 different species of trees in India which produce oil bearings. The following graph shows the reduction at various levels by the use of Bio-Diesel blends with effect of engine temperature. (Fig. 3)

If B100 i.e.100% blend of Bio-Diesel is in use, then the Unburnt Hydrocarbons will be reduced to 67%, Carbon Monoxide to 48%, CO_2 to 47% approx. and Nitrogen Oxide may vary by some percent or it may increase. [7,8,11]



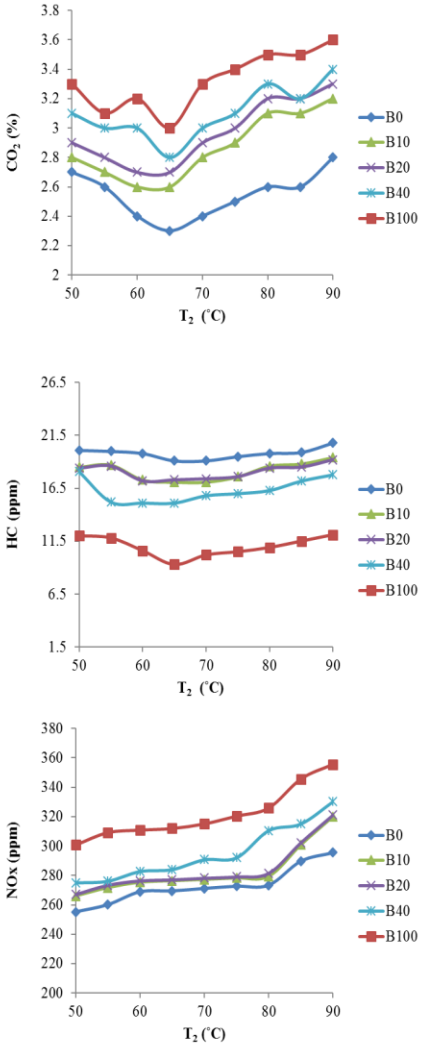


Fig. 3 Effect of engine operating temperature on emissions (diesel and bio diesel blends in CI engine)

If B20 i.e.20% blend of Bio-Diesel is in utilization, then the Unburnt Hydrocarbons will be reduced to 20%, Carbon Monoxide to 12%, Particulate Matter to 12% and Nitrogen Oxide may increase by 10%. But here the Nitrogen oxide problem may be minimized by using the catalytic converters.

4.2.4 Battery Operated Vehicles

The vehicles use the battery power to move the vehicle. The batteries are recharged by conventional trickle charging method or alternators to charge the same, where as yet inventions are in progress to charge the battery fully on alternators. Now in India "REVA" car is popular for battery operated vehicle and some other companies have launched two wheelers. As of now, these vehicles run with 40 to 80 km/hour. By these battery powers, operated vehicles exhaust emissions will zero, as no fuel is burned to produce energy.

4.2.5 Hydrogen fueled vehicles

Hydrogen is high in energy content as it contains 120.7 MJ/kg, which is the highest for any known fuel. However, its energy content compared to volume is rather low. This poses challenges with regard to its storage for civilian applications, when compared to storage of liquid fossil fuels. When burnt, hydrogen produces water as a by-product and is, therefore, environmentally friendly. Although no CO_2, etc. will be produced, if hydrogen is burnt in air, yet NOx will be formed at high temperatures. One of the advantages of hydrogen as a fuel is that it can be used directly in the existing internal combustion engines and can also be used as a fuel in fuel cells for electricity generation. However, when compared to other alternatives, use of hydrogen in transport sector appears to be more beneficial as it is possible to store hydrogen on-board.

4.2.6 Solar Operated Vehicles

Solar Photo Voltaic method is used with solar panels placed on the vehicles and designed as per the Aerodynamic necessities of vehicles. By using solar, the batteries can be recharged and with the battery power, the vehicles can operated where no tail pipe emissions will release. Yet more innovative efforts have to make to attract the people towards solar operated vehicles.[6,9,12]

5. Conclusions

With reference to above detailed discussion on available data and sustainable measures it clearly indicates that in the recent past the emission control technologies for motor vehicles have experienced dramatic improvements, driven by increasingly stringent emission standards. The over all amount of pollutants emitted from a modern car with advanced emission control technology is only 15% of those from a car before pollution controls were introduced. Besides technical measures, economic instruments have also been widely adopted to help enforce challenging emission standards. As a result of the growing pressure to eliminate vehicular emissions, motor vehicles with zero emissions have appeared, such as electric cars and fuel-cell vehicles. Though still with some more awareness the Urban Vehicular Emissions can be reduced.

1. The usage of bicycles for short distance will give tremendous effect to reduce the environmental pollution.
2. Research shows that well maintained perfect condition vehicle generate low exhaust emissions.
3. Use of mass transport systems like electric buses, metros etc protect the environment very well.
4. Alternative fuels like LPG, CNG, Biofuels are much more helpful to reduce exhaust emissions, if properly retrofitted in existing vehicles.
5. Ensure that cooling system of engine working properly,

because it is remarkably helpful to reduce exhaust emissions.
6. The engine operating temperature range 60-70^{0}C plays an important role on fuel consumption and exhaust emissions.
7. Some engine/system design modifications related to engine heat transfer are still required for much better emission output.
8. Latest technological equipped vehicles will be helpful to reduce air pollution.
9. Switching over to hybrid vehicles like duel fuel, plug-in battery operated etc are quite beneficial for environment.

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Commonwealth Energy and Sustainable Development Network (CESD-Net)

CESD-Net is a major global initiative in energy and sustainable development. The objective of network is to promote energy and sustainable development in commonwealth countries.
Focussing on Multidisciplinary Research, Promoting Future Low Carbon Innovations, Transferring Knowledge and Stimulating Networking among Stakeholders to Ensure the UK Achieves World Leading Status in Energy and Sustainable Development. https://www.weentech.co.uk/cesd-net/

The 1st International Conference on Energy, Environment and Economics (ICEEE 2016) was held at Heriot-Watt University, Edinburgh, EH14 4AS, UK, 16-18 August 2016. ICEEE2016 focused on energy, environment and economics of energy systems and their applications. More than fifty eight delegates from 31 countries with diverse expertise ranging from energy economics, solar thermal, water engineering, automotive, energy, economics and policy, sustainable development, bio fuels, Nano technologies, climate change, life cycle analysis etc. made conference true to its name and completely international. During conference total 51 oral presentations and six posters were shared between delegates. The presentations showed the depth and breadth of research across different research areas ranging from diverse background. ICEEE2016 aimed:

- To identify and share experiences, challenges and technical expertise on how to tackle growing energy use and greenhouse gas emissions and how to promote sustainability and economical, cost effective energy efficiency measures.

In total 11 technical sessions and two invited talks both from academia and industry provided insight into the recent development on the proposed theme of the conference. Preparation, organisation and delivery of the conference started from July 2015 and further co-ordinated by vibrant team of Conference Centre, Heriot Watt University. Conference organisers would like to acknowledge support from the sponsors particularly World Scientific Publication ltd and its team members for the delivery of the conference. Organisers are also thankful to all reviewers who contributed during peer review process and their contributions are well appreciated. At the end and during vote of thanks following awards have been announced and we would like to congratulate all well deserving delegates.

- Best Paper –Academia: Amela Ajanovic, EEG, TU Vienna, Austria
- Best Paper – Student : Christian Jenne,University of Duisburg-Essen, Germany
- Best Poster – Student: Yoann Guinard, University of New South Wales, Sydney, Australia
- Best Poster – Academia: E. Salleh, Universiti Kebangsaan Malaysia, Malaysia
- Active Participation Award - Yoann Guinard, University of New South Wales, Sydney, Australia

At the end we would like to extend our gratitude to all of you for your participation and hopefully welcome you again during ICEEE2017.

Editors:
Dr. Singh is Senior Scientist at Indian Agricultural Research Institute, New Delhi, India. Her area of expertise are bio energy and bio fuels, environmental engineering, carbon accounting and renewable energy integration for rural development.
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