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International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com

Vehicular Emission Control Techniques

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A B S T R A C T

The automobiles will always play an important role in the transport system. With the sheer increase in population and living standard, the transport vehicles as well as car population is increasing day by day. In addition to this there is steep increase in the number of two wheelers during the last few decades. All these are adding up to the exhaust pollution and particularly in metros as density of these vehicles in metros are very high. The main pollutants contributed by I.C. engines are CO, NO_x unburned hydro-carbons (HC) and other particulate emissions. Other sources such as Electric power stations industrial and domestic fuel consumers also add pollutions like NO_x, SO_2 and particulate matters. In addition to this, all fuel burning systems emit CO_2 in large quantities and this is more concerned with the Green House Effect which is going to decide the health of earth. Lot of efforts is being made to reduce the air pollution from petrol and diesel engines and various regulations for emission limits are also imposed in USA and in a few cities of India. An extensive analysis of energy usage and pollution shows that alternative power systems are still a long way behind the conventional ones. Further developments in petrol and diesel engines, combined with improvements in the vehicles, will make fuel consumption reduction of 40% or more in the future cars. This, in turn, will reduce the CO_2 emissions, a gas which is mainly responsible for the greenhouse effect.

Keywords: Emission, automobiles, pollutants.

Certain terms used in the Vehicular Emission Control Techniques are as follows:

- NO_X: Nitrogen oxide is a chemical compound of oxygen and nitrogen that is formed by reacting with each other during combustion at high temperatures, mainly combustion.
- CO: Carbon Monoxide is a colorless, odorless, tasteless, toxic gas.
- CO_2: Carbon Dioxide is a colorless gas with a density about 60% higher than that of dry air.
- SO_2: Sulfur dioxide is a colorless gas or liquid that has a strong, odorous smell.
- Particulate Matters: It is a mixture of solid particles and liquid droplets found in the air.
- Green House Effect: The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without this atmosphere.

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1. Introduction

The need to control the emissions from automobiles gave rise to the computerization of the automobile. Hydrocarbons, carbon monoxide and oxides of nitrogen are created during the incineration process and are emitted into the atmosphere from the tail pipe. There are also hydrocarbons emitted as a result of vaporization of gasoline and from the crankcase of the automobile.

The IC Engine is known as one of the major sources of air pollutants in the environment. The fuel oxidation process in the engine generates not only useful power, but also a considerable amount of pollutant emissions including carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbon (HC), nitrogen oxide (NO_x), and particulate matter (PM). CO_2 is mainly responsible for the global warming issues it creates a reflective layer in the atmosphere that reflects heat from the Earth back to the Earth's surface increasing the Earth's average temperature. CO is a very dangerous substance since it reduces the oxygen carrying capacity of the blood stream. The high flame temperature generated during combustion process is responsible for NO_x formation which causes various health problems and also contributes to acid rain and global warming issues. The development of efficient IC engines with low emissions is necessitated by strict regulations on exhaust gas composition and fuel economy. Increasing concern over the potential global warming effects, reducing the exhaust emissions and increasing the fuel economy of IC engines become an important area of research.

The emission can be reduced by using smoke suppressant additives, using particulate traps, SCR (Selective Catalytic Reduction) etc. In today's world, the Internal Combustion (IC) Engine is the key to the entire transportation sector. Without the transportation performed by the millions of vehicles on road and at the sea, we would not have reached modern living standards. Petrol and Diesel are at the present principal fuels used for IC Engines. These fuels are on the verge of getting extinct and during combustion these fuels release a substantial amount of pollutants into the atmosphere and create environment related problems.

2. Literature Survey

- The work described in this paper titled, "Exhaust Emissions and Its Control Technology for an Internal Combustion Engine", explains about the different type of emissions coming out from the SI and CI engines and their effect. He also briefs about the exhaust gases coming out from the vehicles and their impact in various fields. He has also explained about the controlling techniques and various equipment's used to measure the pollutants.
- In this project titled, "Exhaust emissions and its control methods in compression ignition engines: A review", an effort has been made to brief about the extensive usage of automobiles and their negative impact on the environment. Various techniques that would help to overcome these emissions and increase the engine efficiency. A compressive review of diesel engine performance and emission characteristics is given in this paper.

3. Methods to Reduce Emission in SI Engine

3.1. Positive Crankcase Ventilation Valve

The purpose of the positive crankcase ventilation (PCV) system is to take the vapors produced in the crankcase during the normal combustion process, and redirecting them into the air/fuel intake system to be burned during combustion. These vapors dilute the air/fuel mixture, they have to be carefully controlled and metered so as not to affect the performance of the engine. This is the job of the positive crankcase ventilation (PCV) valve. At idle, when the air/fuel mixture is very critical, just a little of the vapors are allowed in to the intake system. At high speed when the mixture is less critical and the pressures in the engine are greater, more of the vapors are allowed in to the intake system.

When the valve or the system is clogged, vapors will back up into the air filter housing or at worst the excess Pressure will push past seals and create engine oil leaks. If the wrong valve is used or the system has air leaks, then engine will vainly get rough, or at worst engine oil will be sucked out of the engine.

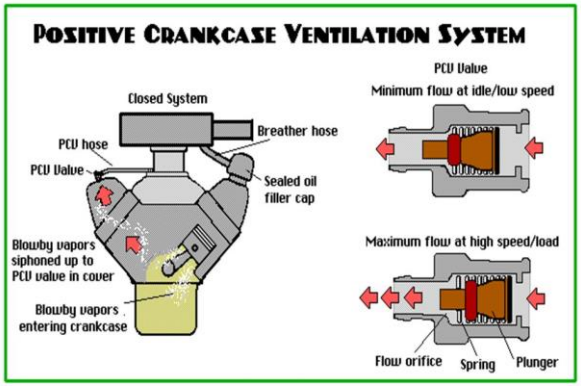

Fig 1: Positive Crankcase Ventilation Valve

3.2. Exhaust Gas Recirculation Valve

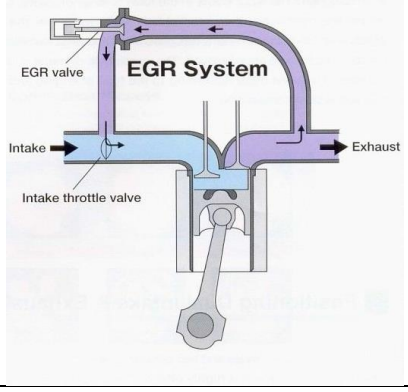

Fig 2: Exhaust Gas Recirculation System

Fig 3: Exhaust Gas Recirculation Valve

The purpose of the exhaust gas recirculation valve (EGR) is to meter a small amount of exhaust gas into the intake system; this dilutes the air/fuel mixture so as to lower the combustion chamber temperature. Excessive combustion chamber temperature creates oxides of nitrogen, which is a major pollutant. While the EGR valve is the most effective method of controlling oxides of nitrogen, in it's very design it adversely affects engine performance.

The engine was not designed to run on exhaust gas. For this reason the amount of exhaust entering the intake system has to be carefully monitored and controlled. This is accomplished through a series of electrical and vacuum switches and the vehicle computer. Since EGR action reduces performance by diluting the air /fuel mixture, the system does not allow EGR action when the engine is cold or when the engine needs full power.

3.3. Air Injection

Since no internal combustion engine is 100% efficient, there will always be some unburned fuel in the exhaust. This increases hydrocarbon emissions. To eliminate this source of emissions an air injection system was created Combustion requires fuel, oxygen and heat. Without any one of this combustion cannot occur.

Inside the exhaust manifold there is sufficient heat to support combustion, if we introduce some oxygen than any unburned fuel will ignite. This combustion will not produce any power, but it will reduce excessive hydrocarbon emissions. Unlike in the combustion chamber, this combustion is uncontrolled, so if the fuel content of the exhaust is excessive, explosions that sound like popping will occur.

There are times when under normal conditions, such as deceleration, when the fuel content is excessive. Under these conditions we would want to shut off the air injection system. This is accomplished through the use of a diverter valve, which instead of shutting the air pump off diverts the air away from the exhaust manifold. Since all of this is done after the combustion process is complete, this is one emission control that has no effect on engine performance. The only maintenance that is required is a careful inspection of the air pump drive belt.

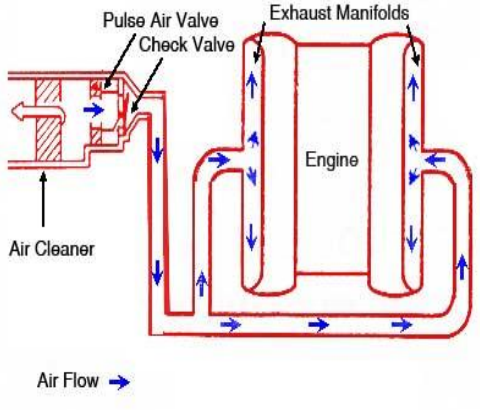

Fig 4: Air Injection System

3.4. Catalytic Convertor

Automotive emissions are controlled in three ways; one is to promote more complete combustion so that there are less by products. The second is to reintroduce excessive hydrocarbons back into the engine for combustion and the third is to provide an additional area for oxidation or combustion to occur. This additional area is called a catalytic converter. The catalytic converter looks like a muffler. It is located in the exhaust system ahead of the muffler. Inside the converter are pellets or a honeycomb made of platinum or palladium. The platinum or palladiums are used as a catalyst (a catalyst is a substance used to speed up a chemical process). As hydrocarbons or carbon monoxide in the exhaust are passed over the catalyst, it is chemically oxidized or converted to carbon dioxide and water. As the converter works to clean the exhaust, it develops heat. The dirtier the exhaust, the harder the converter works and the more heat that is developed. In some cases the converter can be seen to glow from excessive heat. If the converter works this hard to clean a dirty exhaust it will destroy itself. Also leaded fuel will put a coating on the platinum or palladium and render the converter ineffective.

4. Methods to Reduce Emission in CI Engine

4.1. Particulate Filter

Diesel particulate filters (DPF) also called as ‘particulate traps’ have been developed to filter out PM from the diesel exhaust gases to meet very stringent emission limits. Alumina coated wire mesh, ceramic fiber, porous ceramic monoliths etc., have been studied as filtration media. Presently, ceramic monolith of honeycomb type structure is used to trap the particulate matter as the gas flows through its porous walls. These filters are also termed as ‘ceramic wall flow filters’. A ceramic honeycomb type particulate filter is shown in Fig. 5. In this cellular structure, alternate cells are plugged at one end and open at the opposite end. The exhaust gas enters the cells that are open at the upstream end and flows through the porous walls to the adjacent cells. The adjacent cells are open at the downstream end from where the filtered gas exits .to the atmosphere. Flow path of gas through walls of the filter is also shown in Fig 5

Some advantages of wall flow filters over other filtration media are:

- The wall flow filters have a large filtration surface area per unit volume
- The pore size of walls can be controlled to provide gas flow without excessive pressure drop
- Very high filtration efficiencies close to 98% are possible with acceptable pressure drop.

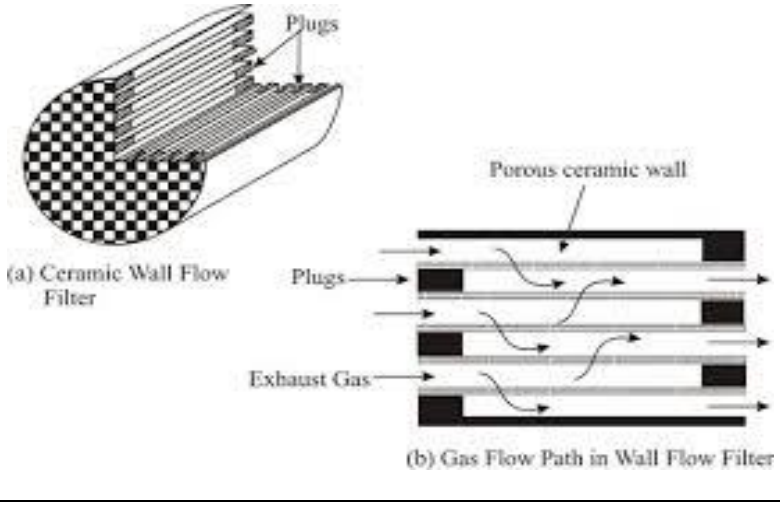

Fig 5: Particulate Filter

4.2. Selective Catalytic Reduction

Selective Catalytic Reduction (SCR) is an advanced active emissions control technology system that injects a liquid-reductant agent through a special catalyst into the exhaust stream of a diesel engine. The reductant source is usually automotive-grade urea, otherwise known as Diesel Exhaust Fluid (DEF). The DEF sets off a chemical reaction that converts nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide (CO_2), natural components of the air we breathe, which is then expelled through the vehicle tailpipe.

SCR technology is designed to permit nitrogen oxide (NO_x) reduction reactions to take place in an oxidizing atmosphere. It is called "selective" because it reduces levels of NO_x using ammonia as a reductant within a catalyst system. The chemical reaction is known as "reduction" where the DEF is the reducing agent that reacts with NO_x to convert the pollutants into nitrogen, water and tiny amounts of CO_2. The DEF can be rapidly broken down to produce the oxidizing ammonia in the exhaust stream. SCR technology alone can achieve NO_x reductions up to 90 percent.

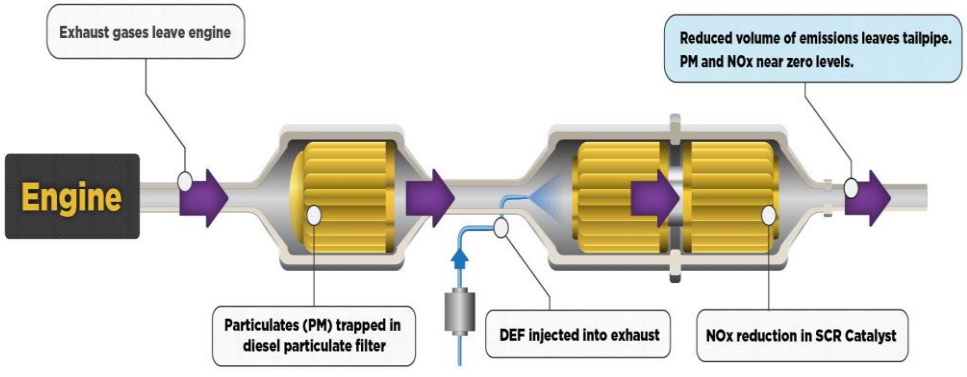

Fig 6: Selective Catalytic Reduction

4.3. Control of Odor

It is very difficult to estimate the odor produced by the diesel engine because the lack of standard tests has not allowed much work to be done in this direction. Catalytic odor control system muffler and or catalyst container are underdevelopment and it has been found that certain oxidation catalysts if used under favorable conditions reduce odor intensity, but the tests are still going on.

5. Emission Reduction

5.1. Modification in SI Engine to Reduce Emission

- Multi-port fuel injection system to completely replace carburetors (These systems have a fuel injector for each cylinder, usually located so that they spray right at the intake valve. These systems provide more accurate fuel metering and quicker response)
- Electronic engine management to accurately regulate fuel supply to cylinders by sensing various engine parameters.
- 4-valve system to replace 2-valve system, improved combustion chamber design and improved inlet manifold design for axial stratification of charge.
- Turbo-charger (A turbocharger, colloquially known as a turbo, is a turbine-driven forced induction device that increases an internal combustion engines efficiency and power output by forcing extra compressed air into the combustion chamber)
- Turbo-compounded engines; they are found to be up to 18 percent better than the conventional engines.
- Variable Valve Activation (VVA) is an automotive piston engine technology which varies the height a valve opens in order to improve performance, fuel economy or emissions. There are two main types of VVL: discrete, which employs fixed valve lift amounts, and continuous, which is able to vary the amount of lift. Provides improved charge control of SI engines, reducing fuel consumption by 5 per cent at low/medium speed and 13 per cent at full engine speed.

5.2. Modification in CI Engine to Reduce Emission

- Commercial Vehicle Emission Control:
  Several improvements are needed. These could be achieved through redesigning of engines and application of new technologies by the improvement in fuel injection system and use of higher injection pressure.
- Passenger Car Diesel Engine:
  In India, Indirect Injection (IDI) diesel engines are commonly used in passenger cars. Due to the pricing policies of fuels, the running cost of diesel cars is lower than those of petrol cars. Diesel engines are popular for taxis.

Major directions for engine development to control different pollutants are as follows:

HC emission control requires:

- Low sac volume nozzles
- Complete combustion of injected fuel
- Minimum lube consumption.

NOx emission control is helped by:

- Cooling of intake air before entering the engine
- Retarded combustion
- Moderate air motion.

Particulate emission control is helped by:

- High injection pressure
- Fine fuel atomization
- Intensive air motion
- Minimum lube consumption

6. Emission Effects

Since 1970, transportation, in particular the combustion of gasoline and diesel in vehicles, has received increasing attention as a source of air pollution at both local and global scales.

6.1. Local Effects:

Traffic represents one of the largest sources of primary air pollutants in urban areas. Large amount of vehicle exhaust emissions will have seriously adverse effects on human health. Assessing the effects of air quality management strategies in urban areas is a major concern worldwide. In addition, worldwide epidemiological studies show a consistent increase in cardiac and respiratory morbidity and mortality from exposure to vehicle exhaust pollution. Both in urban and residential regions, this has become the main areas of toxic compound emissions from the unrestrained use of vehicles burning fossil fuels. In these areas, the population is very sensitive to vehicular pollution.

6.2. Global Effects:

On a global scale, people are more concerned about air pollution and global climate change which are contributed to by vehicle exhausts. Combustion engines contribute to greenhouse gas accumulation in the atmosphere. There are many climate researchers who support the view that emission of heat trapping gases into the atmosphere, particularly CO_2, from the combustion of fossil fuel, cause global warming. The concentration of CO_2 is currently rising by 2 ppm (parts per million) annually (Patrick and Damon, 2008). Transport contributed to an estimated 19% of global GHG (greenhouse gas) emissions in1971, but rose to 25% in 2006. Reductions of CO_2 emissions from transport can be achieved by using energy saving vehicle technologies, which relies on cleanly produced bio fuels, such as biodiesel and ethanol.

Chemical Pollutants	Effects
Lead	Brain damage and behavioral disorders
Beryllium	Promotes lung diseases
Cadmium	Produces kidney and lung disease
Mercury	Induces tremors and skin eruption
Nickel	Causes dizziness and nausea
Carbon monoxide	Prevents blood from carrying oxygen, can cause symptoms like headache, dizziness and nausea

Fig 7: Emission Effects

6.3. How to Improve the Emission Efficiency?

- Catalytic converters for gasoline exhaust: To reduce the vehicles emission example is three-way catalytic (TWC) converters used in gasoline vehicle emission control systems.

  The three catalysis processes are described in the list below (Reduction in emissions with Catalytic Converters, 2009):

  - Reduction of NO_x to O_2 and N_2: $2NO_x \rightarrow XO_2 + N_2$;
  - Oxidation of CO to CO_2: $2CO + O_2 \rightarrow 2CO_2$;
  - Oxidation of unburned hydrocarbons (HCs) to CO_2 and H_2O: $CXH\ (2X+2) + [(3x+1)/2]\ O_2 \rightarrow xCO_2 + (x+1)\ H_2O$

- Catalytic converters for diesel exhaust.
- Improving the Exhaust Gas Recirculation (EGR).
- Advanced new technology on particulate filters (DPFs)

6.4. Euro Norms:

The exhaust gases from IC engines mainly contain unburned hydrocarbons (HC), carbon mono oxide (CO), and nitrogen oxides (NO), which are mainly responsible for air pollution which causes health hazards and bad effects on the crops also. Therefore, the govt. has imposed on emission standards which limit the amount of pollution emitted by the engine into the atmosphere. The govt. of India has accepted the emission norms lay down by European countries and these are known as "Euro- Norms"

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Indian Emission Standards (4-Wheel Vehicles)

Standard	Reference	YEAR	Region
India 2000	Euro 1	2000	Nationwide
Bharat Stage II	Euro 2	2001	NCR*, Mumbai, Kolkata, Chennai
		2003.04	NCR*, 13 Cities†
		2005.04	Nationwide
Bharat Stage III	Euro 3	2005.04	NCR*, 13 Cities†
		2010.04	Nationwide
Bharat Stage IV	Euro 4	2010.04	NCR*, 13 Cities†
Bharat Stage V	Euro 5	(to be skipped)	
Bharat Stage VI	Euro 6	2020.04 (proposed)	Entire country

* National Capital Region (Delhi)
† Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Lucknow, Sholapur, Jamshedpur and Agra

Fig 8: Various Norms in India

6.5. Responsibility of an Engineer or Scientists to Improve Environmental Quality:

- Looking for various new updates on Norms and Standards
- Planting or constructing a forest
- Reducing the use of diesel for cars
- Reducing harmful emissions from olefin manufacturing
- Introducing Selective Catalytic Reduction (SCR)

7. Recent Advancement

7.1. Dust Filtration Influence on the Performance of Catalytic Filters for NO_x Reduction:

Particle matter and NO_x emission are the most significant pollutants of combustion processes, particularly so for the conversion of biomass to energy. Currently, reduction of these pollutants is addressed through particle filters and catalytic processes. Therefore, catalytic activation of filter materials seems to be a practical way to reduce NO_x and fine particle emission (PM_{10}) simultaneously at small and medium furnaces. Regularly used methods to achieve this rely on the impregnation process. However, alternatives for materials with low wet ability are needed. An alternative developed and discussed consists of simultaneous synthesis of filter and catalyst through hard template sintering, where the catalyst is integrated into the porous medium during the fabrication of the filter. This sintering method provides an integrated catalytic filter. Through this method, up to 2% of catalyst loading was achieved in the synthesis of four catalytic filters. The performance of these new catalysts was evaluated under downscale industrial conditions and compared with an ordinary impregnated catalyst. Finally, a dust aging treatment was applied on the catalysts in order to see the long-term influence of fine dust particles on the NO_x conversion.

7.2. Gasoline Particulate Filters:

To improve ambient air quality, several countries have adopted regulations setting stringent limits on vehicular tailpipe emissions of particulates. The issue of high particulate emissions has been mostly addressed for diesel vehicles with the widespread adoption of diesel particulate filters (DPFs). Attention is now turned to gasoline direct injection (GDI) technology, which provides improved fuel economy and performance, but also increased particulate emissions, as compared to the port fuel injection (PFI) engines. Europe has set a particle number (PN) limit on emissions from GDI vehicles, while China has expanded that to include all gasoline vehicles. In the USA, these are regulated through particle mass (PM) limits. To meet these regulations, it is anticipated that gasoline particulate filters (GPFs) will be widely applied to gasoline exhaust after-treatment. GPF technology has rapidly advanced, and already a wide range of pore size distribution and cell geometries are being offered to minimize back pressure and offer high ash storage capacity, high filtration efficiency, and, in the case of filters combined with three-way catalytic functionality, high conversion of gas-phase criteria pollutants.

7.3. Discovery That Could Lead to New Catalyst Design to Reduce Nitrogen Oxides in Diesel Exhaust:

Researchers have discovered a new reaction mechanism that could be used to improve catalyst designs for pollution control systems to further reduce emissions of smog-causing nitrogen oxides in diesel exhaust. The research focuses on a type of catalyst called zeolites, workhorses in petroleum and chemical refineries and in emission-control systems for diesel engines. New catalyst designs are needed to reduce the emission of nitrogen oxides, or NOx, because current technologies only work well at relatively high temperatures. The key challenge in reducing emissions is that they can occur over a very broad range of operating conditions, and especially exhaust temperatures.

Perhaps the biggest challenge is related to reducing NOx at low exhaust temperatures, for example during cold start or in congested urban driving. However, in addition to these "transient" conditions, future vehicles will naturally operate at lower temperatures all the time because they will be more efficient. Zeolites have a crystalline structure containing tiny pores about 1 nanometer in diameter that are filled with copper-atom "active sites" where the chemistry takes place. In the new findings, the researchers discovered that ammonia introduced into the exhaust "solvates" these copper ions so that they can migrate within the pores, find one another, and perform a catalytic step not otherwise possible. This copper-ammonia complexes speed up a critical bond-breaking reaction of oxygen molecules, which currently requires an exhaust temperature of about 200 degrees Celsius to occur effectively. Researchers are trying to reduce this temperature to about 150 degrees Celsius.

Conclusion

In spite of great progress, air pollution and climate problems remain at crisis level with millions of premature deaths and CO_2 crossing 400PPM. Vehicles have made substantial progress but much more in the laboratory than in the real world. Manufacturer should be responsible for real world performance and compliance procedures must be strengthened to assure this. Non Road and GDI PN standard needed quickly. It's premature to stop Euro VII and next (2025) stage of CO_2 control should be adopted soon.

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Acknowledgements

This report becomes a reality with the kind support and help of many individuals. I would like to extend a sincere thanks to all of them.

I would like to express my special gratitude to my **Prof. S. A. Pachapuri**, Assistant Professor Department of Mechanical Engineering, KLE Dr. M. S. Sheshgiri College of Engineering and Technology, Belagavi for the valuable guidance and suggestions offered during the preparation of this report

I extend my sincere thanks to **Dr. S. F. Patil,** Head of the Department, Department of Mechanical Engineering, KLE Dr. M. S. Sheshgiri College of Engineering and Technology, Belagavi for being constant source of encouragement during the completion of report.

I take this opportunity to thank **Dr. B. G. Katageri**, Principal KLE Dr. M. S. Sheshgiri College of Engineering and Technology, Belagavi for providing healthy academic environment in the college.

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