NEW TECHNOLOGIES USED IN AUTOMOTIVE EXHAUST SYSTEMS, REVIEW

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ABSTRACT

The exhaust system is an integral part of an automobile. Components such as Exhaust Manifolds, Connector pipes, X, Y, H Pipes, Oxygen Sensors, Resonators, Catalytic Convertors, Selective Catalytic Reduction and Diesel Particulate Filter techniques have evolved greatly. With increasingly stringent emission reforms being passed by governments and increasingly stringent performance requirements being demanded of by customers, the importance of this system is increasing dramatically. The purpose of this paper is to see the new technology being used in this area and analyse the changes in what customers demand as well as what companies are providing.

Keywords: Automotive Exhaust System, SCR, DPF, Connector Pipes.

INTRODUCTION

Exhaust systems have come a long way from their conception. In today’s world, the exhaust systems have changed drastically to improve in the following areas; NVH levels, exhaust levels and performance enhancement. With the advancement of technology and increasing levels of global warming, governments both in India and abroad have reduced emission allowance and have forced automotive companies to employ newer and more efficient technologies. The exhaust gases created in the engine which move through the exhaust manifold into the exhaust transmission pipes. These pipes can be, singular, X/Y/H pipes. The pipes connect to the catalytic converter which make the gases environment friendly. They then proceed to the muffler and resonator. Once the NVH levels have been reduced depending on the quality of vehicle, the exhaust is let out into the atmosphere as exhaust gases. In today’s world, there have been some changes to the components used for better efficiency.
EXHAUST MANIFOLD

The purpose of the exhaust manifold is to collect all the exhaust gases formed during the running of the engine. Most manifolds are made up of cast iron or stainless steel. It consists of exhaust valves of the same number of cylinders, i.e. one or two valve for one cylinder. Depending upon the design of the manifold it can be 4-1 or 4-2-1. It is installed directly onto the engine block. A manifold gasket is attached in between the manifold and the engine block. Gaskets are meant to prevent leakage of air/gases between the manifold and cylinder heads. The gaskets are usually made of copper or asbestos but the higher end gaskets which are used in performance vehicles may be of steel, aluminium, graphite or ceramic composites.

Fig 1: Exhaust Manifold Gasket

Exhaust manifolds are now being designed like headers; the length of each exhaust pipe for each cylinder is equal. This ensures a vacuum is created between each exhaust pulse. This aids in pulling the subsequent pulse in totality from the cylinder after the combustion cycle, improved exhaust flow and improves volumetric efficiency ergo improving brake horsepower. Exhaust manifolds where the length of pipe is same of all cylinders is most effective in the case of in-line engines. Engines with a V or W formation cannot take advantage of this type of manifold. They are essentially multiple V/W engines joined together rather than the misconception of them being 2 or more inline engines joined at an angle. For example, a V8 is misconceived to be two four-cylinder in-line engines joined together at an angle. They behave more like two V4 engines joined. [2] Exhaust manifolds today also vary in type by being either 4-2-1 or 4-1. 4-1 type manifold provides higher output in the higher RPMs and is preferred by performance vehicles. Whereas 4-2-1 type manifold provides better exhaust flow mid-range of the RPMs and hence is preferred by most manufacturers as most production vehicles require mid-range efficiency more than lower or higher RPM efficiency. Improving the midrange efficiency helps in increasing the ease of driving in day-to-day traffic which is what customers want. [3]

Fig 2: 4-2-1 exhaust and 4-1 exhaust
X/Y/H PIPES

The connector pipes have also changed with time. Y pipes equalise the pressure coming from the connector pipes of 6, 8 cylinder engines. Mostly those engines which have V or W formation hence there are two separate pipes coming from opposite sides of the engine. The pressure differences in these two pipes is significant. Some V-type engines have dual exhaust systems with separate exhaust pipes and exhaust systems connected to each exhaust manifold. Dual exhaust systems are more efficient compared to a singular Y-pipe. The flow of gases in a dual exhaust system is better. The X and H pipes equalise this pressure by joining them in an “X” or “H” formation after the gases have been removed from the exhaust manifold. The equalisation of pressure reduces the back pressure improving flow of exhaust gases from the engine to catalytic converter. To improve engine performance, the flow of exhaust gases should be as smooth as possible. Pipe diameter plays a large role in the gaseous flow. The two important factors to gas flow is pressure and velocity of flow. Companies prefer larger pipe diameter as compared to earlier times as it allows for a greater cross-sectional area and better gaseous transfer with minute change in velocity.

In recent Indian manufacturing scenario, we have seen Mahindra & Mahindra make innovative use of these pipes. The XUV 500 have W8/W6/W4 engine configurations. Hence, they use of Y pipes to remove the exhaust gases from the engine, they are reconnected to a single pipe which goes filters the air using a catalytic converter. The filtered air comes out of two exhaust mufflers, providing additional damping and reducing the Noise & Vibrational Harshness (NVH) levels.

Effect of Length and Diameter of Pipe

There are two main pipes used throughout the exhaust system. The primary pipe is the exhaust manifold. The secondary pipe are the collector/connector pipes used after the manifold. The values of diameter and length are determined by number of cylinders, engine capacity and maximum usable RPMs. The diameter of the pipe depends upon the horsepower developed. The pipe diameter can either be larger or smaller to requirement. In the case of larger diameter, the pressure is not built up and scavenging effect cannot take place. If at all the diameter is too small, the flow of the gases is constricted which results in a drop in power. For a 4-2-1 exhaust system the design procedure can be followed from Shah et al \[5\].

![Fig 3: X, Y, H Pipes \[6\]](image-url)
OXYGEN SENSOR \(^7\)

This device was developed by Robert Bosch GmbH in the 1960s and is also called the Lambda Sensor. The purpose of the sensor is to determine the amount of oxygen in its surroundings. It plays a very important role in automotive vehicles in determining the amount of oxygen present in the exhaust gases. By knowing the same, we can improve electronic fuel injection and emission control. They have to observe in real-time if the air-to-fuel ratio of combustion engine is rich or lean. Since the sensor is present in the exhaust system, they do not directly determine the optimality of the air-to-fuel ratio, but when the information of the sensor is coupled with information from other sources, it can be used to improve overall efficiency of the vehicle. A closed loop feedback-controlled fuel injection varies the fuel injector output according to real-time sensor data rather than working with a predetermined (open-loop) fuel map. In addition to the improved efficiency of the electronic fuel efficiency, this method can improve emissions control drastically in improving levels of unburnt HC and nitrogen oxides. The sensor doesn’t calculate the oxygen concentration, but rather the difference between the concentrations of oxygen in the exhaust system to that concentration of oxygen in the air. Rich burn causes a demand of oxygen which results in a voltage build up due to the movement of ions in the sensor layers. A lean burn causes low voltage as there is an oxygen excess.

New vehicles can use this data to improve emission control and improve the vehicle’s efficiency. The Engine Control Unit (ECU) of the vehicle can adjust the concentration of fuel injected in to the engine to improve the type of burn. The ECU can be used to maintain a certain average value of air-to-fuel ratio by using the sensor data. The average can be a pre-determined or real-time value which maintains the efficiency of the vehicle between power, fuel economy and emissions. Various indicators of the sensor indicate different types of situations. HCs in the exhaust indicates unburnt fuel due to a rich mixture. Carbon monoxide results in a slightly rich burn and NOX indicates a lean burn. Failure or damage of the sensor indicates the use of unleaded fuels containing silicon or silicates. The data from the sensor instructs the ECU to continuously adjust the amount of fuel charged into the engine. The engine operates in a slightly lean and slightly rich burn in successive loops. This helps in maintaining an average which is very close to the stoichiometric ratio.

![Fig 4: [a] Zirconia Sensor \(^8\) & [b] Wideband Zirconia Sensor \(^9\)](image_url)
The sensor element is encased in a ceramic cylinder both inside and outside with platinum electrodes and the entire assembly is wrapped in metal gauge. The sensors work effectively at high temperature. When the temperature is at and above 316°C (600°F). Most new sensors are equipped with their own heating elements. There are three main types of oxygen sensors. They are:

1. **Zirconia Sensor**
   Made of zirconium dioxide or zirconia it is based on a fuel cell called the Nerst cell. It gives an output of 0.2V DC to show a lean mixture in which the air entering the system is enough to fully oxidize the fuel to CO and then CO₂. An output of 0.8V represents a rich mixture which contains unburnt HC and low in O₂. The ideal value is approximately 0.45V. The air-to-fuel ratio is 0.5% of the optimum stoichiometric ratio. The advantage of this sensor is that it is most sensitive near the ideal stoichiometric ratio whereas it is very insensitive and ineffective when mixture is very lean or very rich. This is type of sensor is of the “narrow band” type which refer to the narrow range of values it responds to.

2. **Wideband Zirconia Sensor**
   A variation of the zirconia sensor, called a wideband sensor. Has an “electrochemical gas pump”. An electronic circuit containing a feedback loop controls the gas pump current to maintain a constant output of the electrochemical cell. This lets the pump current directly determine the oxygen content in the exhaust. This sensor removes the lean-rich cycling inherent in “narrow band” sensors which allows the ECU to alter the air-to-fuel ratios much more rapidly thereby improving efficiency and emission control.

3. **Titania Sensor**
   This type of sensor is made of titanium dioxide or titania. It doesn’t produce any voltage of its own but alters its electrical resistance owing to the variation in oxygen concentration. The resistance varies depending on the partial pressure of oxygen and temperature. The change in resistance for the sensor is about 1/1000 for a particular temperature for any variation of change in concentration. Since the value for lambda = 1, the value varies 1000 times between rich and lean depending on the temperature. The resistance is low for a rich burn and high for a lean burn. This type is non-linear, responds faster and is comparatively expensive to the zirconia sensor. This is type of sensor is preferred where the risk of water contamination is high. Since the sensor doesn’t require a reference value of ambient air, it reduces the chances of contamination drastically.

**RESONANCE CHAMBER OR RESONATOR**

In most tuned exhaust systems, a resonance chamber or a resonator is used. It is a device which exhibits resonance or behaviour which is similar to resonance. It naturally oscillates at some frequencies which are called its natural frequencies which a greater amplitude. It is used in automobiles with the muffler to reduce the noise and vibrations. The waves enters the chamber and amplifies. When it hits the opposing wall it is reflected back. During this return wave, the new on-coming waves cancel them out. The length of this chamber is calculated in such a way, that this wave leaves the resonator chamber just after the next wave reflects off the outside of the chamber. Ideally, the high-pressure part of the wave that came from the chamber will line up with the low-pressure part of the wave that was reflected off the outside of the chamber wall, and the two waves will cancel each other out.
CATALYTIC CONVERTERS\[10\]

A catalytic converter is a device used to reduce the toxicity of emissions from an internal combustion engine. It works by using a catalyst to simulate a chemical reaction in which toxic by-products of combustion are converted to less toxic substances. There are many makes and models of catalytic converters. Engine fumes are purified through the converter before leaving the vehicle exhaust system. Sound waves and Exhaust gas pass from exhaust manifold to catalytic converter through a pipe. Due to partial combustion, the gases entering inside the catalytic converter consists of Carbon Monoxide (CO), unburned hydrocarbons and oxides of Nitrogen (NOX), which are harmful to the environment.

Catalytic consists of two ceramic ducts. One duct consists of Platinum and Rhodium and other one has Platinum and Palladium. These metals in ducts act as catalysts. Rhodium helps in reduction of oxides of Nitrogen. Catalytic converters may be pellet-type or monolithic-type. A pellet-type converter contains a bed made from hundreds of small beads, and the exhaust gas passes over this bed (Fig 5a). In a monolithic-type converter, the exhaust gas passes through a honeycomb ceramic block (Fig 5b). The converter beads, or ceramic block, are coated with a thin coating of platinum, palladium, or rhodium, and mounted in a stainless steel container. An oxidation catalyst changes HC and CO to CO$_2$ and water vapour (H$_2$O). The oxidation catalyst may be referred to as a two-way catalytic converter (Fig 6a).

Two – Way Catalytic Converters
A two-way or oxidation catalytic converter has two simultaneous tasks:

1. Oxidation of carbon monoxide to carbon dioxide

\[
2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2 \tag{1}
\]

2. Oxidation of hydrocarbons(un burnt & partially burnt fuel) to carbon dioxide & water:-

\[
\text{C}_x\text{H}_{2x+2} + [\{(3X+1)/2\}] \text{O}_2 \rightarrow X\text{CO}_2 + (X+1) \text{H}_2\text{O} \tag{2}
\]
This type of catalytic converter is widely used on diesel engines to reduce hydrocarbon & carbon monoxide emissions.

They were also used on gasoline engines in American & Canadian market automobile until 1981. Because of their inability to control oxides of nitrogen, they were superseded by three way converter.

**Three – Way Catalytic Converters**

Three-way converter is also known as oxidation-reduction converter. Which have been used in vehicle emission control systems in the United States & Canada, many other countries have also adopted stringent vehicle emission regulation that in effect require three-way converter on gasoline powered vehicles.

Both the catalysts are placed in a common housing. However in some instances both the catalysts may be placed separately. A three-way catalytic converter has three simultaneous tasks:

   
   The toxic gas enters into the first ceramic containing Platinum and Rhodium and heat up simultaneously. This causes catalyst to react with the toxic gases. As the gas enters inside, the Nitrogen molecules are the first to react. The catalyst causes the Oxides of Nitrogen to reform into Nitrogen and Oxygen.

   \[
   2\text{NO}_x \rightarrow \text{XO}_2 + \text{N}_2
   \]  

   - (3)

   The gas then flows through the micro ducts of the second ceramic block which consists of Platinum and Palladium.

2. Oxidation of carbon monoxide into carbon dioxide.

   \[
   2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2
   \]  

   - (4)
3. Oxidation of hydrocarbons (non-burnt & partially burnt fuel) to form carbon dioxide & water.

\[ C_{X}H_{2X+2} + [(3X+1)/2)] O_2 \rightarrow XCO_2 + (X+1) H_2O \quad - (5) \]

The exhaust gas now becomes less toxic and comes out from catalytic converter having mixture of Carbon dioxide (CO\(_2\)), Nitrogen (N\(_2\)), Water Vapours (H\(_2\)O).

**SELECTIVE CATALYTIC REDUCTION (SCR)**[11]

It is an emissions control technology that actively injects a liquid-reductant agent through a specialcatalyst in the exhaust stream. This form of emissions control is currently primarily used in the heavy trucking industry. The reductant source is called Diesel Exhaust Fluid. The DEF is an automotive-grade urea which sets of a chemical reaction that converts nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide which are the natural components of air. This technology is designed to allow NOx reduction reactions to take place in an oxidizing atmosphere. It is so called “selective” because it reduces the levels of NOx using ammonia as a reduction catalyst. SCR is a highly effective technology in reduction of NOx levels. It leads to a drop in 90% of this pollutant. The use of SCR in the past was primarily limited to marine vessels including cargo vessels, ferries and tugboats.

The main reason of its popularity and importance is that it is one of the most fuel efficient and cost reductive technologies for emissions control currently. As per the EPA standards, effective from January 2010, the particulate matter (PM) and nitrogen oxide (NOx) levels are near zero levels. The SCR can reduce NOx levels by 90% while simultaneously reducing HC and Co emissions by 50% - 90% and PM emissions by 30% - 50%. In the trucking industry, the use of SCR reports an increase in fuel economy by 3% - 5%.

Despite having an abundance of advantages to reduce emission and improve fuel economy, there are certain downsides. Primarily, the major concern is the replenishing of the DEF on a periodic basis. It has to be carried on an on-board tank. Depending on the vehicle, engine size and usage of the vehicle the size of the tank and rate of replenishment is determined. If designed well, the DEF can be used to ensure the individual driving the vehicle maintains his vehicle’s emissions standards. The tank can be designed such that the driver is warned of a low DEF level and as and when the DEF level reduces below a certain level, the vehicle doesn’t start and the DEF has to be replenished before the vehicle can be used.

**DIESEL EXHAUST FLUID**

It is a non-toxic fluid composed of purified water and automotive grade aqueous urea. It is available in a large range of dispensing and storage methods. DEF tanks range from 23 litres to 87 litres depending on the truck and its application. The tank fill opening is designed so as to accommodate a DEF fill nozzle to ensure only DEF is filled into the tank. A DEF nozzle is very different to a fuel nozzle and a fuel nozzle cannot fit into a DEF tank fill opening.

**DIESEL PARTICULATE FILTER**[12]

It is device designed to remove diesel particulate matter or soot from the exhaust gases of a diesel vehicle. Soot particles are formed by the incomplete combustion if diesel fuel. The quality of fuel burned also has an influence on the formation of these particles. The sulphur content has an influence on the soot particles. Particulate filters have been used in the automotive industry since 1985. The amount and type of exhaust produced by a diesel engine depends upon engine type, engine
capacity and age. Two stroke engines produce more particulate matter per unit power than four stroke diesel engines, as they burn the fuel-air mixture less completely.

DPF’s were never part of the law. Post the California Heavy Truck Rule, the increase in stringent norm for exhaust and emission control has led engine manufacturers to meet the regulations which has increased the use of it in the trucking industry. Multiple cities/countries such as Hong Kong, Japan, Mexico City, New York City, Milan and London have initiated retrofit programs which have led to the use of DPFs in older diesel vehicles. Unlike most catalytic converters which are flow-through devices, a DPF hold bigger exhaust gas particles by forcing the gas to flow through the filter. But, the DPF doesn’t hold smaller particles and the maintenance-free DPFs break the larger particles into smaller ones.

There are six main types of DPFs:

1. **Cordierite Wall Flow Filters**
   Cordierite is a ceramic material that is also used as catalytic converter cores and provides excellent filtration efficiency. It is relatively inexpensive and has thermal properties that make packaging them for vehicle installation very simple. The drawback of this type is the relatively low melting point of about 1200°C. This causes the cordierite substrates to melt during the filtration process.

2. **Silicon Carbide Wall Flow Filters**
   The most popular filter material is Silicon Carbide or SiC. It has a higher 2700°C melting point however it lacks thermal stability which reduces its packaging capabilities. The SiC cores are made of single pieces joined together and larger ones are made into segments. They are joined together with a special cement so that the heat expansion of the core is taken up by the core. These cores are comparatively more expensive than cordierite cores however they can be manufactured in many more sizes and can be replaced with each other.

The characteristics of wall flow diesel particulate filter substrate are as follows:

- Broad band filtration (the diameters of the filtered particles are 0.2-150 µm)
- High filtration efficiency (can be up to 95%)
- High refractory
- High mechanical properties
- High boiling points

3. **Ceramic Fibre Filters**
   These filters are made for multiple types of different ceramic fibres mixed together to form a porous media. They can be made in almost any shape and size. The porosity can be altered to provide high flow and lower efficiency or low flow and high efficiency. These filters have an advantage over wall flow filter design of producing lower back pressure. Ceramic filters remove carbon particulates almost completely including particulates under 100nm diameter with efficiency greater than 95% in mass and greater than 99% in number of particles over a wide range of engine operating conditions. The continuous flow of soot blocks the filters, there is a necessity to “regenerate” the filtration properties of the filter by burning-off the collected particulate on a regular basis. Soot particulates burn-off forms water and CO₂ in small quantity amounting to less than 0.05% of the CO₂ emitted by the engine.
4. Metal Fibre Flow-Through Filters

These cores are made by “weaving” the metal fibres into the monolith. Such cores have the advantage of having an electrical current which is passed through the monolith to heat the core for regenerative purposes. This allows the filter to regenerate at lower temperatures/low exhaust flow rate. These fibres are more expensive than cordierite/silicon carbide cores and are generally not interchangeable considering the electrical requirement.

5. Paper

Disposable paper cores are often used in certain speciality applications. These cores do not allow for any regeneration strategy. Coal mines use these cores extensively. The exhaust gases are first passed through water to cool them after which they are passed through the filter. Whenever a diesel machine must be used indoors for short periods of times, such as forklifts etc.

6. Partial Filters

There are a variety of devices which provide particulate matter filtration between 35% - 50%. They tend to produce higher back pressure than a catalytic converter and less than a DPF. It is a popular choice for retrofits.

DPFs require higher maintenance than catalytic converters. A by-product of oil consumption of normal engines is Ash. This builds up in the filter as it cannot be converted to gas and pass through the walls of the filter. This increases the back pressure.

REGENERATION

It is the process of removing the accumulated soot from the filter. This is done either passively or actively. Passively involves the exhaust heat from the engine in normal operation or by the addition of a catalyst. Actively involves the introduction of high heat into the exhaust system. On-board active filter management can use a large variety of methods to assist regeneration. They are:

a. Engine management to increase exhaust temperature through late fuel injection or injection during exhaust stroke
b. Use of a fuel borne catalyst to reduce soot burn out temperature
c. A fuel burner after the turbo to increase the exhaust temperature
d. A catalytic oxidizer to increase the exhaust temperature, with after injection (HC-Doser)
e. Resistive heating coils to increase the exhaust temperature
f. Microwave energy to increase the particulate temperature

Most active on-board systems use additional fuel, irrespective it is the burning to heat the DPF or provision of extra power to the DPFs electrical systems. Usually a computer monitors multiple sensors that determine back pressure and/or temperature. Based on the determination of these values and a set of pre-defined/preprogramed set of points the computer makes decisions as to when the regeneration cycle is to be activated. Running the cycle too often will drop the back pressure in the cycle to a very low value which shall ultimately result in high fuel consumption. Whereas not running the cycle often enough will drastically increase the chances of engine damage and/or uncontrolled regeneration and possible DPF failure.
Off-board regeneration is suitable for vehicles which are stationary or vehicles which are parked at a central depot when not in use. It involves the DPF be plugged in to a wall/floor mounted regeneration switch or the filter be removed and placed into a regeneration station.

**MUFFLER**[^13]

The purpose of a muffler is to suppress the acoustic pulses formulated in the engine. The acoustic pulse is created during combustion and travels along the exhaust pipes till it propagates out of the tail pipe.

There are primarily two types of mufflers, Dissipative and Reactive mufflers. A dissipative muffler uses sound absorbing material such as Rock wool, interwoven fiber glass or Acousta-fil, to remove energy out of the acoustic motion in the wave, as it travels through the muffler. Reactive silencers, which are commonly used in automotive applications such as cars and bikes, reflect the sound waves back towards the source and prevent sound from being transmitted along the pipe. Expansion chamber mufflers reflect waves by introducing a sudden change in cross-sectional area in the pipe.

Two typical reactive muffler designs are shown in below. The first design, is frequently chosen because of its low cost and because it causes a lower back pressure. The second design, provides more attenuation and is typical of the design recommended by muffler manufacturers. However there is no direction connection between the inlet and the outlet so back pressure is generated that can effect engine performance. This is sometimes referred to as a baffled muffler design.

![Muffler Designs](image)

**Fig 7:** [a] Reactive muffler with two cavities and no flow restriction & [b] Reactive muffler in which there is no direct passage between the inlet and the exit

The above described and pictured muffler design is the most common type, the reverse-flow design, which changes the direction of exhaust flow inside the muffler. Exhaust gases are directed to the third chamber, forced forward to the first chamber, from where they travel the length of the muffler and are exhausted into the tailpipe.

**Design of Muffler**

Muffler design is very detailed process. It involves knowledge and vehicle/engine specific data. First and foremost, we benchmark the vehicle. Performance details such as, engine power, maximum RPM. Other data such as bore diameter and stroke length are also used. We use this data to find Cylinder Firing Rate (CFR) and Engine Firing Rate (EFR) using formulae and data available in Shah et al[^6].
ACTIVE NOISE REDUCTION

Active Noise Control is a technology which is now slowly becoming a reality for cars. It is a simple yet highly effective method of dramatically reducing NVH levels. Active Noise Control refers to the use of additional sound specifically designed to cancel out the first. It consists of a pressure wave which is identical to the sound emitted from the exhaust but with inverted phase. The pressure waves are emitted by speakers which are controlled by microprocessors. The microprocessor monitors the engine operation and the frequencies emitted into the exhaust pipes and forms the necessary sound which is exactly opposite in phase to that emitted by the engine. This can be used for both amplification and reduction the noise levels of the engine.

CONCLUSION

This paper puts a great deal of importance of exhaust technology which is present in today’s vehicles but is yet to make it to India. From the data above we can see that there are certain technologies with which we can reduce the country’s carbon footprint. Technologies like DPF are present currently in high end vehicles. The use of SCR is still not present in the country. Companies and individuals using these vehicles should realise the importance of the enforced government restrictions. The emitted exhaust noise pollution should not be ignored either. Use of better and more suppressive muffler and exhaust technologies will also enhance the overall drivability of the vehicle. Further research that can be done in this area are methods to introduce low cost technology to match SCR and DPF so as to make it available in the emerging/developing countries and not only in developed countries. Low cost commercial vehicles and heavy vehicles also need to include environmentally safe technology as it is these vehicles which are sold in very large numbers.

REFERENCES


