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Review Report on Comparative Analysis of Exhaust Aftertreatment Systems for Diesel Engine to Meet Future Emission Norms in India

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A B S T R A C T

All over the world as we know that agencies, are working to reduce the emissions from the vehicles/ engines, for the same purpose the emission norms are getting stringent day by day. Bharat Stage-VI, TREM-4/5, CPCB IV+ are the next emission norms for Commercial / Passenger vehicles, agriculture tractors and Gensets respectively, which will be applicable in India by April 2020, April 2022, April 2025 and July 2022 respectively. It will bring down NO_x emissions by 68% and PM emissions by 80% in diesel engine vehicles. Major challenge faced by most of the engine manufacturers with improving performance of Heavy-Duty Diesel vehicles is to meet the stringent exhaust emission norms, with least modification in design. Heavy Duty Diesel Engines have been recently equipped with various electronically controlled components, such as Turbocharger, Fuel Injection Pump or Equipment, Exhaust Gas Recirculation (EGR), SCR etc. for emission reduction. Simplicity of design is to be maintained by optimizing the available emission control technique in order to achieve the emission norms in cost effective manner. The purpose of this research work is to provide information on the increasing stringent emissions from the vehicle, Tractors & Gensets playing a destroying role in human health and global ecology, being a part of the society, everyone has the responsibility to take measures to reduce and to contribute for lower emission and the norms from the government going to be stringent. Vehicle or the final product must be optimized for lower emissions and to meet the future emission norms we need after treatment devices to reduce the emission to near zero.

Keywords: CPCB IV+ , PM , NO_x, EGR, BSFC, DI, TREM, BS, EU

1. INTRODUCTION

Today's diesel engines are well established as a serious and very promising power train solution in the world market. In on road vehicles, DC electricity and agriculture equipment's, diesel engines are the dominating power source. This is due to the significant improvements of these engines, especially the DI (Direct Injection) ones, in combination with the absence of reliable and economic alternative solutions that would cover partially the demand in these areas. Moreover, today's technological status reveals clearly that diesel engines will remain the dominating power source in transportation, construction and agriculture for the short and mid-term future. On the other hand, the most difficult task that must overcome is the further reduction of pollutant emissions, mainly oxides of nitrogen (NOx) and particulate matter (PM), to extremely low levels to meet the future emission legislation. This could be faced today using two main technologies:

1) Lessening of pollutant formation in the engine combustion chamber
2) Lessening using after treatment technology at silencer.

The basic mechanism involved in the formation of pollutants inside the Direct Injection diesel engine combustion chamber, is the mixing and combustion of injected fuel. During survey for the project, it is found that any effort that results in the decrease of either NOX or soot has an undesirable effect on the other exclusively on brake specific fuel consumption (BSFC) and power.

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1.1. Emission Norms

The first emission standards were published in India in 1991 for gasoline vehicles and in 1992 for diesel vehicles, and were followed by the mandatory installation of catalytic converters in gasoline vehicles and the introduction of unleaded gasoline fuel into the market.

On April 29, 1999, the Supreme Court of India ruled that all automobiles in India must fulfil EU (Euro) I or India-2000 emission standards by June 1, 1999, and Euro-II will be mandatory in the NCR zone by April 2000. Car manufacturers were not prepared for this transition, and the implementation date for Euro-II emission standards was not imposed in a subsequent ruling.

In the year 2002, the Government of India acknowledged the report provided by the Mashelkar Committee. This committee proposed a road map for India's implementation of Euro (EU)-based emission standards. It also proposed a phased implementation of impending emission standards, with limits implemented first in large cities and then extended to the remainder of the country after a few years.

The National Auto Fuel Policy was formally broadcasted in 2003, based on the recommendations of the Mashelkar group. The strategy for implementing Bharat Stage (BS) rules was established till the year 2010. The strategy also established criteria for car fuels, pollutant reduction from older vehicles, and R&D for air quality data establishment and health management.

1.2. Comparison between Bharat Stage and Euro Stage Norms

Bharat Stage (BS) emission standards have been designed to meet the specific needs and demands of Indian environmental circumstances. The differences are primarily due to environmental and local requirements, despite the fact that emission rules and standards are same.

For example, the (EU-3) Euro III emission standard is tested at sub-zero temperatures in European countries, however in India, where average yearly temperatures range from 24°C to 28°C, the test is eliminated.

Another significant difference is the maximum speed at which the vehicle is evaluated. A speed of 90 km/h is specified for (Bharat stage) BS-III emission regulations, whereas a maximum speed of 120 km/h is specified for Euro-III emission norms, with emission limitations remaining the same in both circumstances.

Aside from the emission restrictions, the test technique includes finer points as well. In European countries, the mass emission test readings in g/km (measurement unit) on chassis dynamometer require a loading of 100 kg weight in addition to the empty automobile weight (Europe). In India, BS-III emission rules require an additional 150 kg load to achieve the desired inertia weight, owing to road load circumstances.

The mixing and burning of injected gasoline is the fundamental mechanism involved in the creation of pollutants inside the Direct Injection diesel engine combustion chamber. During the project's survey, it was discovered that any effort that results in a reduction in either NOX or soot has an unfavorable influence on the other, namely on brake specific fuel consumption (BSFC) and power.

1.3. Present Scenario

Pollution is currently a major worry, and it is occurring as a result of the abundant use of fossil fuels. The traditional way of power generating to produce energy is one of the sources of environmental pollution. If a picture of the world's pollution is taken, countries that utilize non-conventional power produce far less pollution than those that use conventional power. Climates all across the world have changed as a result of tremendous pollution, and people are experiencing a variety of difficulties as shown in Figure 1.1.

Today's immobile sources of air pollution are combustion of fuel for electricity and heat, other burning such as forest fires, industrial and commercial activities, diluters, and aerosols. Highway vehicles such as cars, trucks, buses, and motorcyclists contribute, as do off-highway vehicles.

India is estimated to experience about one million premature deaths each year as a result of air pollution (both outdoor and indoor), with children bearing the brunt of the burden. India is a major contributor to the "Atmospheric Brown Cloud" above the Indian Ocean due to its high levels of PM, NOx, and mercury emissions.

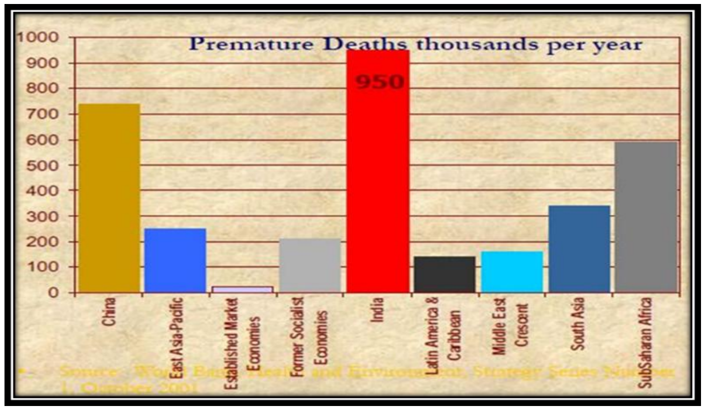

Figure 1.1: Premature mortality due to air pollution by region of the world
Source: (Projected annual averages for 2001-2020, reference WHO)

1.4. Existing and Future Emission Norms

Initially emission norms were introduced in India in 1991 for gasoline and 1992 for diesel fuel vehicles. These were trailed using Catalytic converter for gasoline vehicles and the introduction of unleaded gasoline fuel. The existing and Future upcoming emission norms are as follows as per Table no. 1,2 (Existing Emission norms in INDIA) and Table no. 3,4 and 5 (Future Emission norms).

Table 1. Existing emission norms in India

VEHICLE CATEGORY	EMISSION STANDARS	EFFECTIVE DATE
2 - Wheeler	BS-6	1st APR'2020 with mandate
3 - Wheeler	BS-6	1st APR'2020 with mandate
4 - Wheeler ≤ 3.5 Ton	BS-6	1st APR'2020 with mandate
4 - Wheeler > 3.5 Ton	BS-6	1st APR'2020 with mandate
Agricultural Tractor / CEV	TREM III A	1st APR'2010 1st APR'2011
Generator sets	CPCB-II	1 JULY'2014

Table 2. Future emission norms in India.

VEHICLE CATEGORY	EMISSION STANDARS	EFFECTIVE DATE
Agricultural Tractor / CEV	TREM - 4	1st APR'2021
Agricultural Tractor / CEV	TREM - 5	1st APR'2024
Generator sets	CPCB - IV+	Under Discussion

Table 3. Future emission norms in India for CEV/TREM-4.

Emission Parameters →		CO	HC	NOx	PM	TEST CYCLE
Category, kW	Applicable with effect from	g/kWh				
37 P< 56	1st APR' 2021	5.0	4.7 (HC+NOx)		0.025	NRSC and NRTC
56 P< 130		5.0	0.19	0.4	0.025	
130 P < 560		3.5	0.19	0.4	0.025	

Table 4. Future emission norms in India for CEV/TREM-5.

Emission Parameters →		CO	HC	NOx	PM	PN	TEST CYCLE
Category, kW	Applicable with effect from	g/kWh				#/kWh	
P < 8	1st APR' 2024	8.0	7.5 (HC+NOx)		0.4	----	NRSC
8 P< 19		6.6	7.5 (HC+NOx)		0.4	----	NRSC
19 P< 37		5.0	4.7 (HC+NOx)		0.015	1×1012	NRSC and NRTC
37 P< 56		5.0	4.7 (HC+NOx)		0.015	1×1012	
56 P< 130		5.0	0.19	0.4	0.015	1×1012	
130 P < 560		3.5	0.19	0.4	0.015	1×1012	
P □ □ 560		3.5	0.19	3.5	0.045	----	NRSC

Table 5. Future emission norms in India for CPCB IV+ (Power Generation Diesel Engines).

CPCB IV+						
Power Rating Category	Emissions (g/kWhr)					(m^{-1})
	NOx	CO	HC	NOx+HC	PM	Smoke (Should Not Exceed At Any Load)
kW ≤ 8	-	≤ 3.5	-	≤ 7.5	≤ 0.3	≤ 0.7
8 < kW ≤ 19	-	≤ 3.5	-	≤ 4.7	≤ 0.3	≤ 0.7
19 < kW ≤ 37	-	≤ 3.5	-	≤ 4.7	≤ 0.03	≤ 0.7
37 < kW ≤ 56	-	≤ 3.5	-	≤ 4.7	≤ 0.03	≤ 0.7
56 < kW ≤ 225	≤ 0.4	≤ 3.5	≤ 0.19	-	≤ 0.02	≤ 0.7
560 < kW ≤ 800	≤ 0.67	≤ 3.5	≤ 0.19	-	≤ 0.03	≤ 0.7

Note: - Effective date of CPCB IV+ norms on PAN INDIA basis is under discussion.

2. Literature Review

Timothy V. Johnson did research on diesel engine emission control in 2001 and published the journal and article in SAE. This summary of research covers developments from year-2008 in diesel emission regulations, diesel engine technology, NOx (Nitrogen oxides), particulate matter-PM, and HC hydrocarbons control. Europe is confirming the futuristic Euro-VI heavy-duty (HD) emission regulations with the intent of technology harmonizing with the USA. Novel particle number standard will be adopted in futuristic emission norms. California is seeing to tighten the light duty fleet average to USA Tier-2 Bin-2 levels, and CO2 mandates are evolving in Europe for light duty vehicles, and in the USA for all kind of vehicles. The LD engine technology is intensive on rationalizing to bring lower CO2 emissions allowed by advancing in boost and exhaust gas recirculation (EGR). The concepts are shown for achieving Bin- 2 emission level and norms. Heavy-duty engines will generate de-NOx systems as an option for meeting the rigorous NOx level regulation, although de-NOx systems allow for lower fuel usage and are expected to be employed in Heavy-duty engines. SCR (selective catalytic reduction) is being used to manage NOx (nitrogen oxides) in a variety of applications. The focus is on cold operation, system optimization, and catalyst durability. The performance of lean NOx traps (LNT) is evolving, and precious metal prices are falling. DE sulfation is being enhanced, and novel compositions based on ceria and alumina are being developed. The development of low-NOx catalysts is being reformed. Diesel particulate filter technology is being optimized, which will aid in further cost reduction. Fresh Diesel particulate filter regeneration techniques have been labelled, as have new insights into the fundamentals of soot-catalyst contact and its impact on the pore structure of a diesel particulate filter. Finally, an update on diesel oxidation catalysts is offered, demonstrating potential options for advanced interior engine combustion [1].

Kemal Altinisik based on toxic emissions from diesel engines, vehicles, and exhaust after treatment systems Diesel engines are very efficient, dependable, and long-lasting, with minimal running costs. These characteristics make diesel engines the most popular choice for heavy duty (HD) vehicles. Over time, there has been a substantial surge in interest in diesel engines. In addition to the widespread usage of diesel engines, which have numerous advantages, diesel engines play a critical part in worldwide environmental pollution concerns. Diesel engines are regarded as one of the biggest contributors to environmental pollution caused by exhaust emissions. They are also responsible for a variety of health concerns. Many policies have been implemented globally in recent years to reduce the consequences of diesel emissions on human health, the environment, and the environment. Many investigations on diesel exhaust pollutants emissions and after-treatment emission control systems have been funded. The emissions from diesel fuel engines and their control systems are investigated in this study. The main four pollutants emitted by diesel engines are discussed, namely carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM), and nitrogen oxides (NOx), as well as the control systems for them, which include the diesel oxidation catalyst (DOC), diesel particulate filter (DPF), and selective catalytic reduction (SCR). Each type of emission and its control method is thoroughly investigated. This study sheds light on the impact of exhaust emissions on human health and the environment, as well as the legalized constraints on exhaust emissions around the world [2].

Johnson and By Tim were conducted a review of diesel engine emissions and their control. It discusses recent developments in rules to limit diesel emissions, engine technologies, and nitrogen oxide and particulate matter remediation. The EU (European Union) is presently the geographical focus of regulatory development, with Euro-5 and Euro-6 standards for light-duty (LD) engines completed for implementation in 2009 and 2014, respectively. The laws are far more strictly enforced than those in the United States, however there are options for adapting European vehicles to the American market. Europe is only now beginning to report heavy duty (HD) regulations for 2013 and beyond. Engine technology is making highly encouraging progress, with clean engine combustion techniques in active development, mostly for light duty (LD) vehicle applications in the United States. The effort with heavy duty (HD) engines is more rigorous than with previous approaches, but it will result in a plethora of engine aftertreatment options for complying with the stringent US-2010 emission rules. SCR (selective catalytic reduction) is being used to manage NOx (nitrogen oxides) in a variety of applications. Zeolite catalysts will be used to support this technology in the United States and Japan, as well as maybe in select Euro-5 submissive applications. Low temperature (LT) operations, secondary emissions, and system optimization are highlighted. Lean Nitrogen Oxides traps (LNT) are being measured for light duty (LD) applications and are operative up to about 60% to 70% de-NOx efficiency. There is growing interest in improving LNT performance by incorporating an integrated Selective Catalytic Reactor (SCR) that uses ammonia (NH3) created in the Lean Nitrogen Oxides traps during rich regenerations. The DPF (Diesel particulate filter) technology is in the process of being optimized and cost-cutting. Very sophisticated management tactics are being used, which opens up choices, such as the usage of novel filter materials and alternative system designs [3].

Koltsakis Anastasios Recently, a novel metal foam material for diesel particle filtering was described. Extensive testing revealed that a radial flow design idea with graded foam porosity has the potential to achieve filtering efficiencies of the order of 85 percent or higher at low pressure drop. When a catalytic wash coat is applied to the foam, it demonstrates improved gas mixing and consequently greater conversion efficiencies at high space velocities. Furthermore, the wash coated foam demonstrated high catalytic regeneration rates due to strong soot-catalyst interaction. The current research focuses on a novel "cross-flow" design approach for improved filtration/pressure drop trade-offs, as well as the usage of foam as an oxidation catalyst substrate. Experimentation begins with small-scale reactors and progresses to genuine exhaust testing on the engine bench, vehicle testing on the chassis dynamometer, and on-road testing. It is demonstrated that the foam structure has good mass-transport capabilities, allowing for precious metal and catalyst volume savings in oxidation catalyst applications [4].

Koichiro Nakatani His research focuses on the reduction of PM (Particulate Matter) and NOx (Nitrogen Oxides) in diesel engines. The Diesel Particulate NOx Reduction System (DPNR) is a new aftertreatment model that has been developed for the instantaneous and continuous reduction of PM (particulate matter) and NOx (nitrogen oxides) in diesel exhaust emissions. This system incorporates innovative catalyst technology as well as internal diesel engine combustion technology, allowing for rich operating conditions in diesel fuel engines. The Diesel Particulate NOx Reduction System (DPNR) catalytic converter comprises a newly developed porous ceramic structure coated with a NOx (Nitrogen Oxides) reduction catalyst. The new Diesel Particulate NOx Reduction System (DPNR) catalyst decreases Particulate Matter (PM) and Nitrogen Oxides by more than 80%. (NOx). The idea and performance of emission control systems are defined in this study. The intricacies of the Particulate matter (PM) oxidation mechanism in the Diesel Particulate NOx Reduction System (DPNR) are pronounced exclusively [5].

3. Methodology

The study of literature review is completed wherein reference of various papers and reviews have been studied in which use and methods of using aftertreatment is mentioned i.e., with the help of aftertreatment devices how we can reduce the exhaust emissions and also to meet desired emission norms.

4. Gap Analysis

In the literature review it is worked out that how aftertreatment system works, how much benefit it will give if the system is being used to reduce the emissions, selection of materials in aftertreatment systems is explained, how the fuel injection system selection and its implementation will help us to improve combustion viz a viz performance and to reduce cost impact of aftertreatment system on final product. It is also helpful to reduce engine exhaust emissions before catalytic convertor to reduce the cost impact of precious metal selection and loading capacity of aftertreatment system as well as to eliminate few systems from the final aftertreatment layout. In all the research work is done to reduce exhaust emissions mainly NOx and PM emissions coming out from diesel/ gasoline fuel engines, passenger cars and heavy-duty vehicles to meet BS-VI (Bharat stage -VI) emission norms in INDIA. For off-road variable speed engines (Tractors and construction equipment application) and fixed speed engines (Gen-sets) study, research work and analysis are to be done.

5. Out Come of Literature Review

The out of the literature is as follows as shown in Table 6.

Table 6: The out of the literature

S. no	Title	Author	Year	Outcome
1	Diesel Emission Control	Timothy V. Johnson	2001	Development of diesel engine emission regulations over a period of time, its consequences and usage of aftertreatment devices to meet the emission norms.
2	The pollutant emissions from diesel-engine vehicles and exhaust aftertreatment systems	Kemal Altinişik	2014	In this review and research emissions from diesel fuel engines & its control systems are studied.
3	Diesel Engine Emissions and Their Control	Johnson, By Tim	2008	In this research diesel engine emissions are studied i.e., how secondary emissions are affecting, use of de-NOx technologies and its impact on overall product cost are also studied.
4	Catalytic automotive exhaust aftertreatment	C.KoltsakisAnastasios	1998	In this research the application of catalytic converters (CC) for the abolition of main emission pollutants are studied.
5	Simultaneous PM and NOx Reduction System for Diesel Engines	Koichiro Nakatani	2002	In this research the development of new aftertreatment DPNR (Diesel Particulate - NOx reduction System) is done to control NOx and PM emissions.

6. Conclusion

The upcoming new technologies, as well as developments of existing technologies are mandatory for the diesel engines to meet the upcoming / Future emission norms and engine efficiency challenges. The diesel engines industry has realized and is further exploring several approaches to achieve the NOx and PM emission reductions required by future emission standards. Other than the Aftertreatment (post-combustion) exhaust emission control devices, new methods for in-cylinder emission reduction and Fuel / lubricant formulations that reduce engine-out emissions is also needed, in order to achieve the up-coming stringent emission norms in a cost effective and simple manner. More focused approach towards alternate fuel, hybrid and electric vehicles is also required keeping the increasing air pollution and current environmental conditions in view.

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