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Emissions Reduction using Catalyst Converter

Yegireddi Shireesha, Bade Venkata Suresh, P Govinda Rao

Department of Mechanical Engineering, Engineering, GMRIT, Rajam, India

Abstract: Toxic converter is a vehicle emissions control device that converts toxic pollutants in exhaust gas to less toxic pollutants by catalyzing a redox reaction (oxidation or reduction). Catalytic converters are used with internal combustion engines fueled by either petrol (gasoline) or diesel-including lean-burn engines. This application can also be applied to exhaust systems in automobiles.The catalyst used in the converter consists of mostly some metal such as platinum, palladium and rhodium. Platinum is used as a reduction catalyst and as an oxidation catalyst. Although platinum is a very active catalyst and widely used, it is very expensive and not suitable for all applications. Rhodium is used as a reduction catalyst, while palladium is used as an oxidation catalyst. In some cases, cerium, iron, manganese and nickel are also used. In the present work we replaced platinum with cerium just because of its high cost. Here ferric ammonium sulphate, ferrous ammonium sulfate and cerium are used as oxidizing agent and manganese dioxide and nickel oxide are used as reducing agents. By using these metallic powders the toxicity of the exhaust gases are reduced. Here we conducted tests on three vehicles of different cubic centimeters. And pollution tests are conducted at Road Transport Organization Srikakulam.
Key Words: Catalyst converter, toxic pollutants, nickel oxide, ammonium ceric nitrate, ferrous ammonium sulphate, manganese dioxide.

Introduction:

Exhaust gas or flue gas is emitted as a result of the combustion of fuels such as natural gas, gasoline, petrol, biodiesel blends, diesel fuel, fuel oil or coal. According to the type of engine, it is discharged into the atmosphere through an exhaust pipe, flue gas stack or propelling nozzle. It often disperses downwind in a pattern called an exhaust plume.

Emission standards focus on reducing pollutants contained in the exhaust gases from vehicles as well as from industrial flue gas stacks and other air pollution exhaust sources in various large-scale industrial facilities such as petroleum refineries, natural gas processing plants, petrochemical plants and chemical production plants. However, these are often referred to as flue gases. Catalytic converters in cars intend to break down the pollution of exhaust gases using a catalyst. Scrubbers in ships intend to remove the sulfur dioxide (SO2) of marine exhaust gases. The regulations on marine sulfur dioxide emissions are tightening, however only a small number of special areas worldwide have been designated for low sulfur diesel fuel use only.

To reduce the fuel consumption and emissions Michel, P et.al[1] a 3WCC multi-0D model is built from physical equations. To analyze how operation with ethanol influence catalytic converter performance de Almeida, P et.al [2] conducted study on three catalytic converters were aged in a vehicle operating on a chassis dynamometer by 30,000 km. To reduce emissions with some bio- fuels Vallinayagam, R et.al [3] using urea as reducing agent, along with a CC (catalytic converter) has been implemented in the exhaust pipe. To analyze the flow field and catalytic reaction of full-size automotive catalytic converters Su, Q et.al [4] Employed computational fluid dynamics package coupled with CHEMKIN code. To recover platinum group metals (PGMs) from spent automotive catalytic converters with a smaller environmental load Sasaki, H et.al [5] discussed the reactions on Zn-treated catalysts in the solution. To evaluate the performance of a two-stroke, single cylinder, spark ignition (SI) engine, with alcohol blended gasoline Krishna, M et.al [6] copper coated engine provided with catalytic converter with sponge iron as catalyst. To ensure conversion of all pollutants Millet, C. N et.al [7] identified that catalytic reactions were affected by the soot deposit. Continuous oxidation of soot by NO2 also induced a slower NOx storage rate. To accelerate the optimization process Faghihi, E et.al [8] developed a mathematical model of the SCR catalytic converter is replaced with the neural network model. The conversion efficiency of a catalytic converter, mounted on a vehicle equipped with a 2.8 l spark ignition engine Silva, C. M et.al [9] were evaluated under steady state operating conditions. For a computational study of a proposed recuperative catalytic converter intended for the catalytic combustion of lean methane streams Litto, R et.al [10] identified that the monolith comprised of higher thermal conductivity material is more effective in enhancing the temperature in the reactor.

Emissions of many air pollutants have been shown to have variety of negative effects on public health and the natural environment. Emissions that are principal pollutants of concern include:

- Hydrocarbons - A class of burned or partially burned fuel, hydrocarbons are toxins. Hydrocarbons are a major contributor to smog, which can be a major problem in urban areas. Prolonged exposure to hydrocarbons contributes to asthma, liver disease, lung disease, and cancer. Regulations governing hydrocarbons vary according to type of engine and jurisdiction; in some cases, "non-methane hydrocarbons" are regulated, while in other cases. Methane is not directly toxic, but is more difficult to break down in a catalytic converter, so in effect a "non-methane hydrocarbon" regulation can be considered easier to meet. Since methane is a greenhouse gas, interest is rising in how to eliminate emissions of it.
- Carbon monoxide (CO) - A product of incomplete combustion, carbon monoxide reduces the blood's ability to carry oxygen; overexposure (carbon monoxide poisoning) may be fatal. Carbon Monoxide poisoning is a killer in high concentrations.
- NOx - Generated when nitrogen in the air reacts with oxygen at the high temperature and pressure inside the engine. NOx is a precursor to smog and acid rain. NOx is the sum of NO and NO2.[1] NO2 is extremely reactive. NOx production is increased when an engine runs at its most efficient (i.e. hottest) part of the cycle.
- Particulate matter – Soot or smoke made up of particles in the micrometer size range: Particulate matter causes negative health effects, including but not limited to respiratory disease and cancer.
- Sulfur oxide (Sox) - A general term for oxides of sulfur, which are emitted from motor vehicles burning fuel containing sulfur. Reducing the level of fuel sulfur reduces the level of Sulfur oxide emitted from the tailpipe.

The average emissions of exhaust gases are given in table 1.

Table: 1 The Average passenger car emissions are

Component	Emission Rate (grams/mile)	Annual pollution emitted (pounds)
Hydrocarbons	2.80 grams/mile (1.75 g/Km)	77.1 pounds (35.0 kg)
Carbon monoxide	20.9 grams/mile (13.06 g/Km)	575 pounds (261 kg)
NOx	1.39 grams/mile (0.87 g/Km)	38.2 pounds (17.3 kg)
Carbon Dioxide Green House Gas	0.916 pounds/mile(258 g/Km)	11,450 pounds(5,190 kg)

Light-Duty Vehicle, Light-Duty Truck, and Medium-Duty Passenger Vehicle—Tier 2 Exhaust Emission Standards are given in table 2

Table: 2 Exhaust Emission Standards

Component	Emission Rate	Annual pollution emitted
NMOG	0.075 grams/mile (0.046 g/Km)	2.1 pounds (0.95kg)
Carbon Monoxide	3.4 grams/mile (2.1 g/Km)	94 pounds (43 kg)
NOX	0.05 grams/mile (0.0305 g/Km)	1.4 pounds (0.64kg)
Formaldehyde	0.015 grams/mile (0.0092 g/Km)	0.41 pounds (0.19kg)

Methodology:

Green Exhaust gas is a toxic converter that can be used to convert toxic pollutants into eco-friendly gases. The arrangement of a toxic converter is a long pipe which is assembled with cotton-bed arrangement and slit arrangement.

Chemicals Used:

In this present work the chemicals used are:

a. Nickel Oxide
b. Ammonium Ceric Nitrate
c. Ferrous Ammonium Sulphate
d. Manganese Dioxide

a. Nickel Oxide:

It is the inorganic compound with the chemical formula Ni_2O_3. Nickel oxide is very reactive reductant which is used to reduce the toxic pollutants. Generally these nickel oxides are used in nickel-iron battery as one of the component, and also used in fuel cells. It is the precursor to many nickel salts, for use as specialty chemicals and catalysts. Black nickel oxide is the precursor to nickel salts, which arise by treatment with mineral acids. Nickel oxide is a versatile hydrogenation catalyst.

Properties:

Chemical formula : NiO
Density : 6.67 g/cm3
Melting Point : 1,955°C

Figure: 1 Nickel Oxide

b. Ceric Ammonium Nitrate:

Cerium ammonium nitrate ((NH4)2Ce(NO3)6) is a one-electron oxidizing agent that is used for oxidative addition reactions of electrophilic radicals to alkenes, enabling intermolecular and intramolecular carbon-carbon and carbon-heteroatom bond formation. CAN also oxidizes secondary alcohols into ketones and benzylic alcohols into aldehydes.

Cerium ammonium nitrate is used as a catalyst for several types of transformations. They are classified into the following categories:

1. Reactions involving the formation of carbon-carbon bond.
2. Reactions involving the formation of carbon-heteroatom bond.

Properties:

Chemical formula : H8N8CeO18
Density : 1.1 g/cm3
Melting Point : 107 to 108 °C

Figure: 2 Ceric Ammonium Nitrate

c. Ferrous Ammonium Sulphate:

In analytical chemistry, this salt is preferred over other salts of ferrous sulfate for titration purposes as it is much less prone to oxidation by air to iron. The oxidation of solutions of iron is very pH dependent, occurring much more readily at high pH. The ammonium ions make solutions of Mohr's salt slightly acidic, which slows this oxidation process. Sulfuric acid is commonly added to solutions to reduce oxidation to ferric iron.

Properties:

Chemical formula : (NH4)2Fe(SO4)2·6H2O
Density : 1.86 g/cm3
Melting Point : 100 to 110 °C

Figure: 3 Ferrous Ammonium Sulphate

d. Manganese Dioxide:

This blackish or brown solid occurs naturally as the mineral pyrolusite, which is the main ore of manganese and a component of manganese nodules. Manganese dioxide will speed up a reaction but will not change the results.

Properities:

Chemical formula	:	MnO_2
Density	:	5.026g/cm3
Melting Point	:	535°C

Figure: 4 Manganese Dioxide

Preparation of Wire Mesh:

Initially a PVC pipe is taken, the dimensions of the pipe is length 42cm and 8 diameter. A wire mesh of gauge 1.25mm is fabricated in to required dimensions as shown in the figure 5. These each wire meshes is separately dipped in corresponding chemicals and the chemicals are nickel oxide , manganese dioxide, ferrous ammonium sulphate and ammonium ceric nitrate solutions and placed in the hot air oven to fix the accumulation of chemicals over the mesh. After the adhesion of the chemicals over the surface of wire mesh emery papers are taken as per the required dimensions of the wire mesh and dipped in the same chemicals where the wire mesh is dipped and taken to the oven for drying. After completion of drying process these emery papers are placed in between two wire mesh of same chemical order as shown in the figure 6.

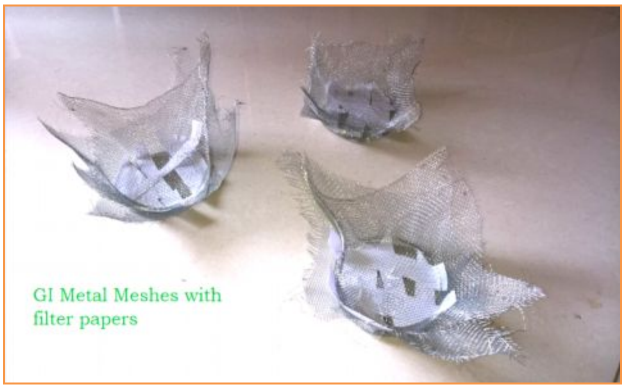

Figure: 5 GI metal meshes

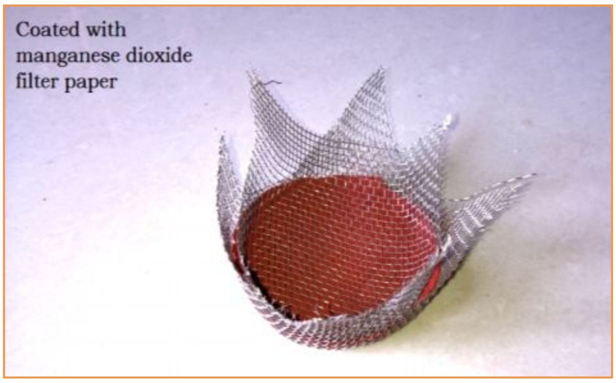

Figure: 6 Mesh with MnO2 filler pqaper

Construction of Bed:

Here in the construction of the bed consists of vertical sectioned PVC pipe and ceramic wool as shown in the figure 7. The entire PVC pipe is divided into four parts and Ceramic wool is placed at that position by dipping each ceramic wool in each chemicals the chemicals are nickel oxide , manganese dioxide, ferrous ammonium sulphate and ammonium ceric nitrate solutions. After that the slits are placed in between the two cotton beds and the remaining half section is joined with the help of bolt and nuts.

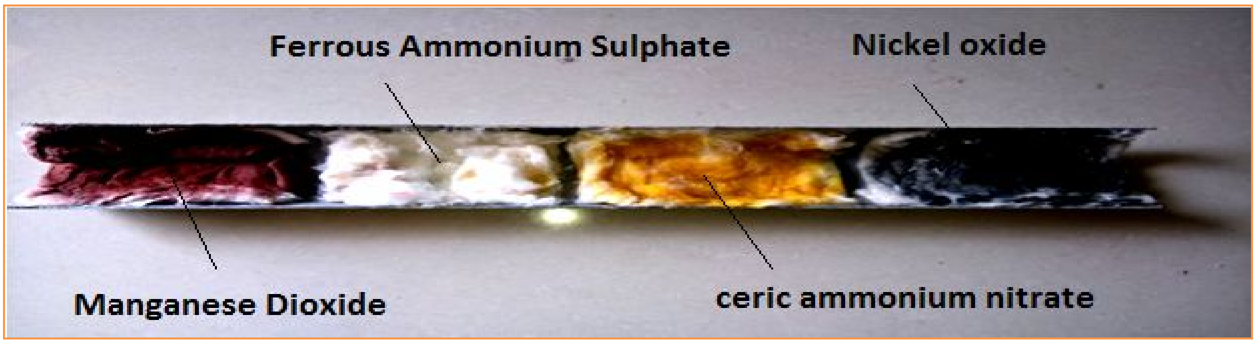

Figure: 7 Sectioned PVC pipe

After having the cotton bed arrangement, we need to have some markings on the pipe to accommodate the meshes inside and for bolting the screws. We keep the meshes gently inside the pipe and bolted with screws carefully. Hence we make sure that the inside portion of the pipe contains the meshes along with the cotton bed arrangement. The two ends of the PVC pipes are closed with nozzle shaped funnel in order reduce the escape of the exhaust gases from the boundaries. The nozzle shaped funnel are made up of galvanized iron sheets gauge 2.

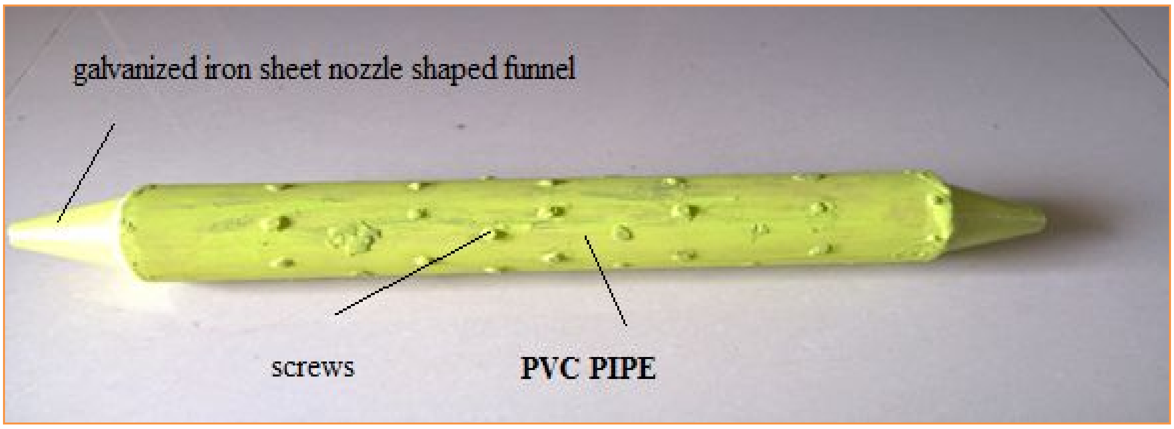

Figure: 8 Design of Catalyst Converter

Results and Discussion:

The exhaust gases of three different vehicle are transferred through the fabricated catalyst converter and identified the toxicity of the exhaust gases. Here the three different vehicles are Royal Enfield, Bajaj Pulsur and Hero Passion. And these results are taken from Road transport Organization Srikakulam.

The following were the reports given by the R.T.A. Department of Andhra Pradesh with and without the converter.

SCFM = Standard cubic feet per minute (SCFM)
SCFH = Standard cubic feet per hour(SCFH)
PPM=Parts per million
UBF=Un Burned Fuels

Vehicles Used:

Royal Enfield Bullet Classic : CC=350
Pulsar 150 : CC=150
Passion Plus : CC=97.2

Without the converter:

a. These are the results observed when the vehicle is kept at idle shown in table 3, means when the vehicle is at initial without acceleration.

Table : 3 Results at Idle condition

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	98	0.0	0	0.047	61.6	14.4	0.363	60	0.353	6	0.035
Pulsar 150	95	0.0	0	0.017	23.1	5.4	0.132	50	0.285	4	0.023
Passion Plus	159	0.0	0	0.053	66.4	15.4	0.633	68	0.648	17	0.162
AVERAGE			0	0.039	50.4	11.7	0.376	59	0.429	9	0.073

b. These are the results observed without using any catalyst converters when the acceleration is given. shown in table 4

Table : 4 Results at acceleration

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	447	0.0	0	0.018	20.5	0.8	0.550	827	22.2	7	0.188
Pulsar 150	461	0.1	27.7	0.023	30.1	1.2	0.833	863	23.9	6	0.166
Passion Plus	529	0.05	15.9	0.021	21.3	0.9	0.677	856	27.2	37	1.173
AVERAGE		0.05	14.5	0.021	24.0	1.0	0.683	849	24.4	17	0.509

c. These are the results observed when the vehicle is kept at cruise shown in table 5, means when the vehicle is travelling at constant speed.

Table : 5 Results at Cruise

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	395	0.0	0	0.013	20.0	1.3	0.478	310	7.35	4	0.095
Pulsar 150	279	0.0	0	0.000	20.0	0.0	0.000	224	3.73	19	0.318
Passion Plus	360	0.0	0	0.015	19.6	2.2	0.423	178	3.85	9	0.195
AVERAGE			0	0.009	13.3	1.2	0.300	237	4.98	11	0.203

d. These are the results observed when the vehicle is kept at deceleration shown in table 6, means when the vehicle is slowly decelerated by decreasing its acceleration.

Table : 6 Results at Deccelaration

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	350	0.0	0	0.061	95.2	72.7	2.00	40	0.840	7	0.147
Pulsar 150	238	0.0	0	0.000	0	0.0	0	42	0.600	10	0.143
Passion Plus	318	0.0	0	0.038	45.7	38.7	0.87	9	0.171	70	1.335
AVERAGE		0.0	0	0.033	43.6	37.1	0.96	30	0.537	29	0.541

With the Converter

a. These are the results observed with converter when the vehicle is kept at idle shown in table 7, means when the vehicle is at initial without acceleration.

Table : 7 Results at Idle condition

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	87	0.0	0	0.032	58.2	10.2	0.312	54	0.296	6	0.029
Pulsar 150	73	0.0	0	0.006	20.6	3.2	0.111	41	0.199	4	0.019
Passion Plus	130	0.0	0	0.043	60.2	11.2	0.577	59	0.742	17	0.166
AVERAGE			0	0.027	46.33	8.2	0.333	51	0.412	9	0.0713

b. These are the results observed with converter when the vehicle is kept at acceleration shown in table 8 means the vehicle gets accelerated with some speed.

Table : 8 Results at acceleration

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	432	0.0	0	0.012	19.8	0.6	0.521	775	20.4	6	0.134
Pulsar 150	453	0.1	25.3	0.019	28.7	1.1	0.729	792	19.7	5	0.154
Passion Plus	515	0.03	13.6	0.016	18.4	0.7	0.537	799	22.4	29	1.154
AVERAGE		0.034	12.95	0.0206	22.3	0.8	0.595	788	20.8	13	0.480

c. These are the results observed with converter when the vehicle is kept at cruise shown in table 9, means when the vehicle is travelling at continuous speed without change.

Table : 9 Results at Cruise

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	287	0.0	0	0.009	16	0.9	0.376	289	6.56	3	0.069
Pulsar 150	243	0.0	0	0.001	0.1	0.2	0.011	197	2.199	11	0.219
Passion Plus	298	0.0	0	0.009	14.2	1.3	0.342	116	1.742	5	0.166
AVERAGE			0	0.0006	10.01	0.8	0.243	200	3.050	6	0.141

d. These are the results observed with converter when the vehicle is kept at deceleration shown in table 10, means when the vehicle is slowly decelerated by decreasing its acceleration.

Table : 10 Results at Deccelaration

Engine Type	Exhaust Flow	Carbon Monoxide		Hydrocarbons				Oxides of Nitrogen		Formaldehyde	
		Vol %	SCFH	Vol%	Lbs/SCF10C	%UBF	Lbs/hr	P.P.M	SCFH	P.P.M	SCFH
Royal Enfield	299	0.0	0	0.054	85.01	61.1	1.521	32	0.541	5	0.122
Pulsar 150	195	0.0	0	0.010	0.11	0.1	0.1	34	0.456	7	0.134
Passion Plus	258	0.0	0	0.016	33.4	20.7	0.53	7	0.096	59	1.02
AVERAGE		0.0	0	0.026	39.5	27.3	0.717	24	0.364	23	0.425

By observing all the results with and without converter for all the three vehicles, it is identified that the there is a decrease in the toxicity in exhaust gases are obtained when we are using catalyst converter.

a. For Carbon monoxide:

- The percentage decrease of SCFH in carbon monoxide during idle, cruise and deceleration condition is 0%
- The percentage decrease of SCFH in carbon monoxide during acceleration condition is 10.68%

b. For Hydro Carbons:

- The percentage decrease of UBF in Hydro carbons during idle condition is 25.6%
- The percentage decrease of UBF in Hydro carbons during acceleration is 20%
- The percentage decrease of UBF in Hydro carbons during cruise is 33.3%
- The percentage decrease of UBF in Hydro carbons during deceleration is 26.4%

The overall % decrease of UBF in hydro carbons is 26.325%

c. For Oxides of Nitrogen :

- The percentage decrease of SCFH in oxides of nitrogen during idle condition is 3.9%
- The percentage decrease of SCFH in oxides of nitrogen during acceleration is 14.75%
- The percentage decrease of SCFH in oxides of nitrogen during cruise is 38.75%
- The percentage decrease of SCFH in oxides of nitrogen during deceleration 32.2%

The overall % decrease of SCFH in Oxides of Nitrogen is 22.4%

d. For Formaldehyde:

- The percentage decrease of SCFH in formaldehyde during idle condition is 2.3%
- The percentage decrease of SCFH in formaldehyde during acceleration is 5.6%
- The percentage decrease of SCFH in formaldehyde during cruise is 30.54%
- The percentage decrease of SCFH in formaldehyde during deceleration 21.44%

The overall % decrease of SCFH in Formaldehyde is 14.97%

Conclusion:

From the above results it is clear that the emissions are reduced by using catalyst converter. The percentage decrease of SCFH in carbon monoxide during acceleration condition is 10.68%, the overall % decrease of UBF in hydro carbons is 26.325%, the overall % decrease of SCFH in Oxides of Nitrogen is 22.4% and the overall % decrease of SCFH in Formaldehyde is 14.97%. So we can suggest this type designs are applicable for the existing models to reduce the toxic emissions.

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