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A NOVEL METHOD TO IMPROVE INTERNAL COMBUSTION ENGINE EMISSION CONTROL & PERFORMANCE PARAMETER: A REVIEW

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ABSTRACT

The paper reviews the technologies available to meet the exhaust emissions regulations for Internal Combustion Engine of, light-duty and heavy-duty vehicles, non-road mobile machinery and motorcycles This includes fast light-off catalysts, more thermally durable catalysts, improved substrate technology, diesel particulate filters, selective catalytic reduction, NO_x absorbers and lean $DeNO_x$ catalysts. The stricter world wide emission legislation and growing demands for lower fuel consumption and anthropogenic CO_2 emission require significant efforts to improve combustion efficiency while satisfying the emission quality demands. Ethanol fuel combined with gasoline provides a particularly promising and, at the same time, a challenging approach.

Extensive usage of automobiles has certain disadvantages and one of them is its negative effect on environment. Carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), sulphur dioxide (SO_2) and particulate matter (PM) come out as harmful products during incomplete combustion from internal combustion (IC) engines. As these substances affect human health, regulatory bodies impose increasingly stringent restrictions on the level of emissions coming out from IC engines.

Modern combustion techniques such as low temperature combustion (LTC), homogeneous charge compression ignition (HCCI), premixed charge compression ignition (PCCI) etc. would be helpful for reducing the exhaust emissions and improving the engine performance. However, controlling of auto ignition timing and achieving wider operating range are the major challenges with these techniques.

KEYWORDS: Diesel Engine, Oxides of Nitrogen, Emission, Particulate Matter, No_x, Lean Burn, Gaseous Fuel, Energy Efficiency, After Treatment, Low Temperature Combustion

INTRODUCTION

The **internal combustion engine** is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine (ICE) the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine. The force is applied typically to pistons, turbine blades, or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy.

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, "total hydrocarbons" are regulated. Technology for one application (to meet a non-methane hydrocarbon standard) may not be suitable for use in an application that has to meet a total hydrocarbon standard. 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.
- **Nitrogen Oxides (NO_x):** Generated when nitrogen in the air reacts with oxygen at the high temperature and pressure inside the engine. NO_x is a precursor to smog and acid rain. NO_x is a mixture of NO, N_2O, and NO_2. NO_2 is extremely reactive. It destroys resistance to respiratory infection. NO_x 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 micrometre size range: Particulate matter causes negative health effects, including but not limited to respiratory disease and cancer.
- **Sulfur Oxide (SO_x):** 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.
- **Volatile Organic Compounds (VOCs):** Organic compounds which typically have a boiling point less than or equal to 250 °C; for example chlorofluorocarbons (CFCs) and formaldehyde. Volatile organic compounds are a subsection of Hydrocarbons that are mentioned separately because of their dangers to public health.

FIVE GASES

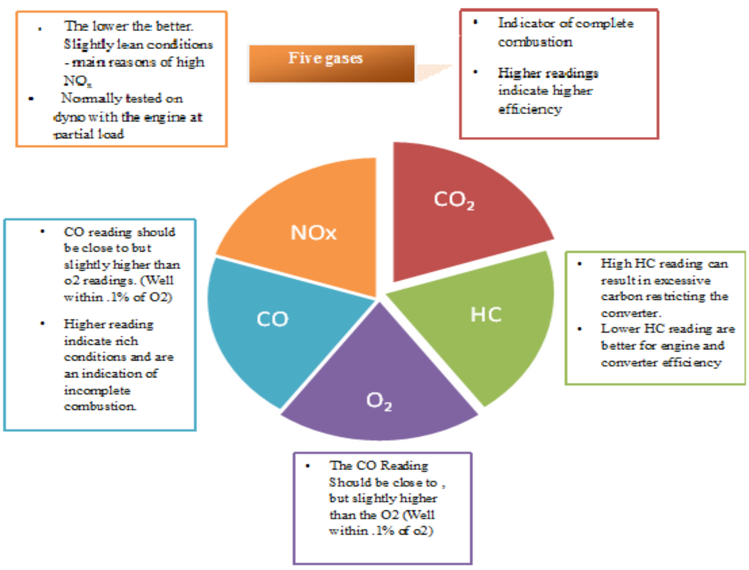

Figure 1

CO_2 — We require High CO_2 readings

- CO_2 is an indicator of complete combustion.
- Higher readings indicate high efficiency.
- A single cylinder misfire in a 4 cylinder engine will reduce the reading by 25% .

O_2 — O_2 is required < 0.5% balanced with CO < 0.5%, but normally not zero

- The O_2 reading should be close to, but often slightly lower than the CO reading (well within 0.1 % of CO).
- High readings indicate a lean condition , that can result in a false code .

CO — < 0.5 % balanced with < 0.5 O_2 , but normally not zero

- CO readings should be close to, but slightly higher than O_2 reading (well within 0.1 % of O_2).
- High readings indicate rich condition and are an indicator of incomplete combustion.

HC — < 35 ppm

- A high HC reading can result in excessive carbon restricting the converter.
- If high HC readings exist along with high O_2 readings , a misfire or cylinder imbalance may be inferred. This may cause the converter to overheat, the shell to glow red and discolor, resulting in substrate melt down.
- Lower HC readings are always better for engine and converter efficiency.

NO_x — The lower the better

- Slightly lean conditions are the main reason for high NO_x readings.
- An exhaust leak will prevent a converter from reducing No_x efficiently.
- NO_x is normally tested on a dyno with the engine at partial load.

Lambda — Should always be "1" or extremely close

- Lambda is a more accurate indicator than AFR because it is the actual balance of air to fuel.
- A converter requires Lambda to be between 0.98 and 1.02 to light off but it will not work at peak efficiency unless Lambda is between 0.995 – 1.005.

Air Fuel Ratio — 14.7 parts air to 1 part fuel or gasoline

- 14.6 – 14.8 is acceptable as long as lambda is "1".
- Lambda is a better measurement parameter, as it indicates true air to fuel balance.
- It is not a theoretical target like AFR of 14.7 : 1.

Figure 2

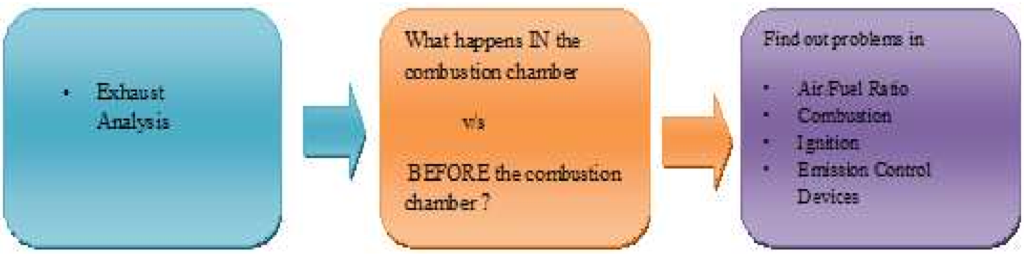

Figure 3

EXHAUST EMISSIONS FROM INTERNAL COMBUSTION ENGINES

Exhaust emissions can be lowered by reducing engine-out emissions through improvements to the combustion process and fuel management, or by changes to the type of fuel or its composition. Emissions control systems – autocatalysts, adsorbers and particulate filters – in combination with good quality fuel (low sulfur content) and enhanced engine management reduce emissions to very low levels. As well as their application in new vehicles and machinery, many emissions control systems can also be applied in retrofit applications to good effect.

EMISSION ANALYSIS

Table 1

Typical Gas Analyzer Readings (at Idle)				
CO_2	O_2	CO	HC	Lambda
14.5 – 16 %	0 – 0.35 %	0.1 – 0.45 %	0 – 35 ppm	0.995 – 1.005

LAYOUT

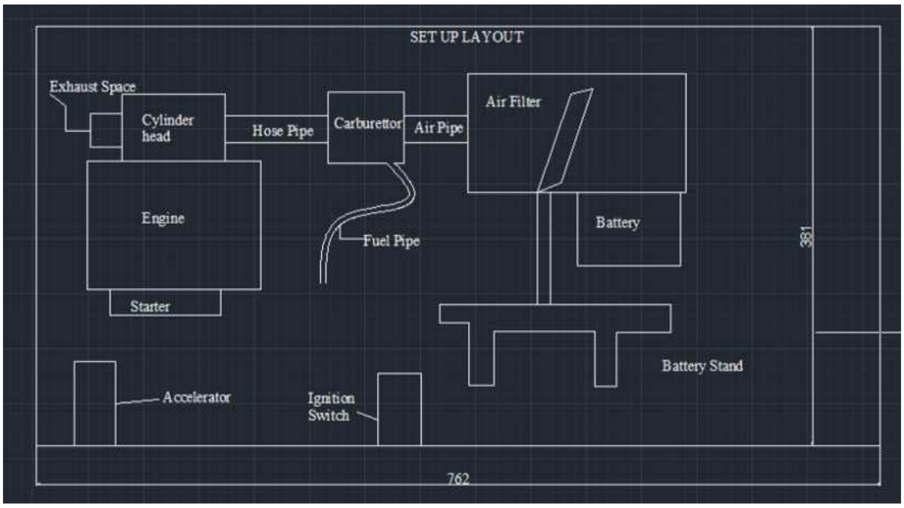

Figure 4: Common Setup Layout Diagram of Internal Combustion Engine and Other Parts

THE IMPORTANCE OF FUEL QUALITY

Fuel and lubricant quality affects the performance of emissions control systems either by preventing the use of a technology unless the fuel quality is improved (the improved fuel is “enabling” the use of that technology) or by “enhancing” the performance of emissions control systems. In this case both the existing fleet and new vehicle registrations benefit. The motor industry has published information on the effects of fuel quality, with recommendations, in the “Worldwide Fuel Charter” (5).

Examples of enabling fuels are unleaded petrol that allows three-way catalysts to be used and ultra-low sulfur fuels required so that NO_x absorbers can be used and which ease the use of catalyst-based Diesel Particulate Filters (DPF). Examples of enhancing fuels are the further reductions in the levels of lead, phosphorus and alkali metals that improve the performance and life of three-way catalysts and the introduction of ultra-low sulfur gasoline and diesel fuels. Reducing sulfur levels all the way down to near-zero delivers improved performance of catalysts.

Also, there are concerns over the use of some metallic additives, with suggestions that their use in gasoline may, under some driving conditions, lead to deposits on exhaust system components such as the oxygen sensor and catalyst. Metallic or other ash-forming materials in diesel fuel will also add to the amount of ash captured by particulate filters and may require the system to be designed so as to allow for the additional ash.

Detergent additives, on the other hand offer positive benefits. Their use helps keep the fuel injection system and combustion system clean, so helping to prolong optimum operating conditions for the emissions control technology.

Table 2: Comparative Analysis Obtained

		Standard Values (at Idle)	Test Readings	
		(Source- BS 2 Norms 2005)	(at Idle)	(at Midrange)
N O R M A L PIPE	CO_2	14.5 – 16 %	1.80	9.70
	O_2	0 – 0.35 %	17.08	5.65
	CO	1.6-1.87	1.49	2.52
	HC	0 – 40 ppm	180	151
	Lambda	0.995 – 1.005	4.486	1.349
	NO_x		8	61
(4) B L A D E SWIRLER	CO_2	14.5 – 16 %	3.50	11.30
	O_2	0 – 0.35 %	13.95	2.99
	CO	1.6-1.87	2.26	2.99
	HC	0 – 40 ppm	254	95
	lambda	0.995 – 1.005	3.142	1.107
	NO_x		5	87
V E N T U R I PIPE	CO_2	14.5 – 16 %	1.60	14
	O_2	0 – 0.35 %	17.24	1.53
	CO	1.6-1.87	1.59	1.00
	HC	0 – 40 ppm	80	32
	lambda	0.995 – 1.005	4.616	1.061
	NO_x		21	38

DESIGN PARAMETERS

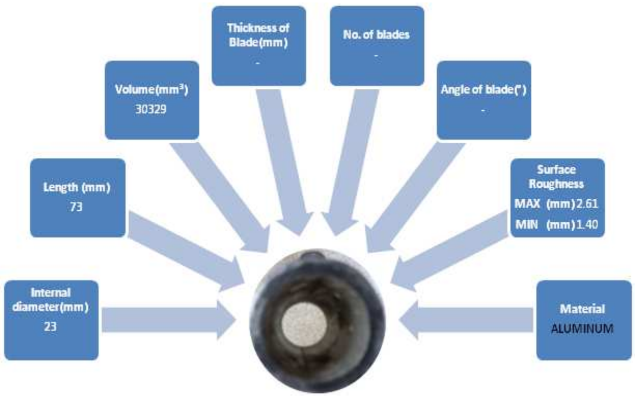

Figure 5: Design Parameters- Existing Inlet Manifold

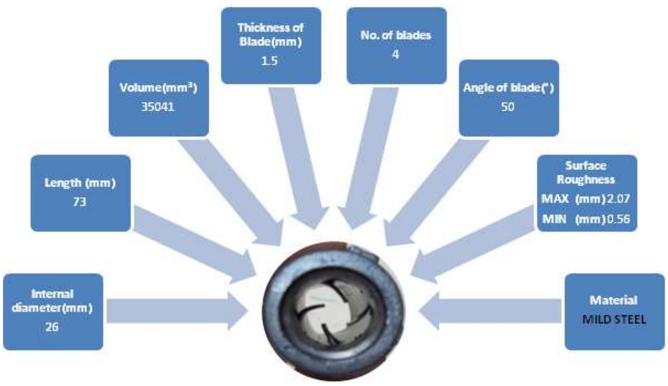

Figure 6: Design Parameters- Four (4) Blade Swirler

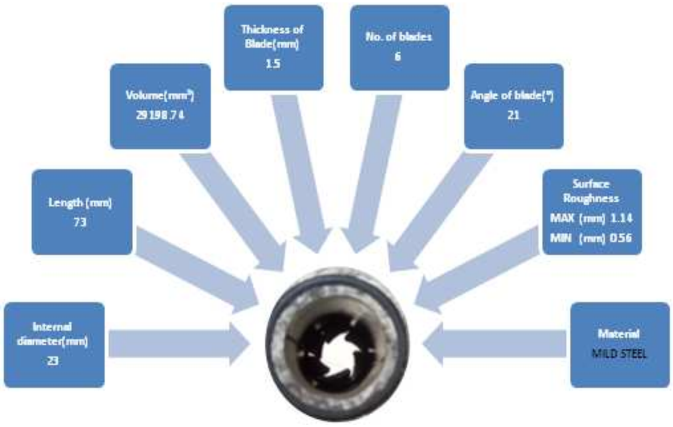

Figure 7: Design Parameters- Venturi Pipe

CATALYST TECHNOLOGIES FOR EMISSIONS CONTROL

The Catalyst

Catalysts are needed to reduce emissions to acceptable levels without dramatically reducing performance and fuel economy. This is true of HC, CO and NO_x, but NO_x is the emission that ismost dependent on the catalyst for emissions compliance.

There are actually two types of catalysts. Reduction catalysts cause NO_x to be reduced into O_2 and N_2. Oxidation catalysts cause HC and CO to oxidize with any available oxygen into CO_2 +H_2O. Unfortunately oxidation will only occur when there is enough free oxygen, and reduction will only occur in a relative absence of free oxygen. Rhodium is generally the most efficient reduction catalyst. Platinum and palladium are used for oxidation. 2-way catalytic converters are oxidation catalysts. They oxidize CO and HC but do not reduce NO_x. 3-way catalysts oxidize and reduce. They oxidize CO & HC and reduce NO_x.

Proper air /fuel mixture control and exhaust oxygen content is required for proper 3-way catalyst performance. In general, oxidation and reduction can not both occur at their highest efficiency at the same time. Reduction efficiency is not at it's highest unless the oxygen content is very low. This usually doesn't happen unless the air/fuel mixture is at least a little bit rich. Oxidation only reaches it's highest efficiency when the oxygen content is fairly high. That happens when the mixture is at least slightly lean. A dual bed catalyst has two separate chambers. Air can be injected in the middle of the catalyst to increase oxygen content in the back half of the converter. The engine can then be run slightly rich to improve NO_x reduction in the front half of the converter.

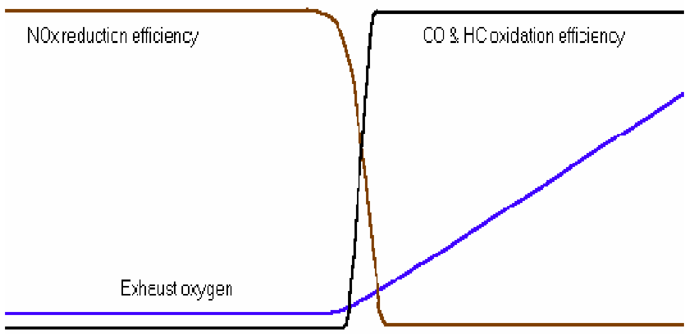

Figure 8

The air that is injected allows high efficiency oxidation of CO & HC in the back half of the converter. This type of converter can allow NO_x reduction to occur in the front bed at maximum efficiency while CO and HC oxidation are occurring in the rear bed at maximum efficiency. It is the injection of air in front of the rear bed that allows both oxidation and reduction to occur at maximum efficiency.

Catalytic Convertor Tests

Cranking Test

There is typically no CO_2 present in the atmosphere. CO_2 is a product of combustion. Therefore any carbon dioxide emissions measured during typical starter draw test, with ignition disabled must be created in the catalytic converter.

A good catalytic converter should be capable of converting the Hydrocarbon fuel (HC) that is pumped through the engine during the starter test to 13% carbon dioxide.

In order to create 13% CO_2 during a starter draw test the following must occur:

- The catalytic converter must be completely warmed up.
- Fuel delivery must be functioning normally. The CO_2 is being created by converting the fuel that is being pumped through the engine.
- Ignition must be completely disabled.

The Test

- Start the engine and drive the car to insure that it is warmed up completely.
- Run the engine at 2000 rpm to insure that the catalytic converter is hot.
- Turn off the ignition or hit the analyzer kill switch.
- IMMEDIATLY after the engine stops, disable the ignition (ground the coil secondary or disconnect the coil

Snap Throttle Test

When the engine is running at a stoichiometric 14.7:1 fuel mixture with no air injection there is very little oxygen in the exhaust. Cars equipped with Carburettors will have higher normal levels of oxygen due to poorer fuel atomization and vaporization. During a snap throttle test CO will increase due to a suddenly rich mixture on acceleration. CO will continue to increase until the O_2 level begins to rise. During this snap acceleration all excess oxygen will be used up by the catalytic converter to convert CO to C O_2. As the O_2 level rises O_2 will be used up by the "CAT" to convert CO to CO_2 and the CO level will begin to drop as O_2 rises. A good "CAT" will therefore prevent the O_2 level from exceeding 1.2% until the CO level begins to drop.

The Test

- Drive the car until the engine and catalytic converter are fully warmed up.
- Disable the air injection system.

- Run the engine at 2000 rpm and wait for stable exhaust readings with Oxygen level no higher than 0.5%. Propane enrichment may be used to reduce oxygen level to 0.5%.
- Snap and release the throttle.
- Watch the CO emissions climb and note the Oxygen level at the instant the CO level peaks. Oxygen level at the instant that Co level peaks should not exceed 1.2%.

NO_x Control Technologies

With the development of lean burn direct injection gasoline engines and the increased use of diesel engines in passenger cars, there is an increasing need for the control of NO_x in lean combustion systems. Lean burn systems limit CO_2 emissions and reduce fuel consumption and so are key technologies for the future.

Selective Catalytic Reduction (SCR)

SCR was originally developed and used to reduce nitrogen oxide emissions from coal, oil and gas fired power stations, marine vessels and stationary diesel engines. SCR technology permits the NO_x reduction reaction to take place in an oxidizing atmosphere. It is called "selective" because the catalytic reduction of NO_x with ammonia (NH3) as a reductant occurs preferentially to the oxidation of NH3 with oxygen SCR technology is now fitted to most new heavy-duty (i.e. truck and bus) diesel engines. Systems are also being introduced on light-duty diesel vehicles and on non-road mobile machinery such as construction equipment. It allows diesel engine developers to take advantage of the trade-off between NO_x, PM and fuel consumption and calibrate the engine in a lower area of fuel consumption than if they had to reduce NO_x by engine measures alone.

NO_x Absorbers or Lean NO_x Traps (LNT)

Lean NOx traps adsorb and store NO_x under lean conditions. A typical approach is to speed up the conversion of nitric oxide (NO) to nitrogen dioxide (NO_2) using an oxidation or three-way catalyst mounted close to the engine so that NO_2 can rapidly be stored as nitrate. The function of the NO_x storage element can be fulfilled by materials that are able to form sufficiently stable nitrates within the temperature range determined by lean operating engine points. Thus especially alkaline, alkaline earth and to a certain extent also rare-earth compounds can be used.

GRAPHICAL REPRESENTATION

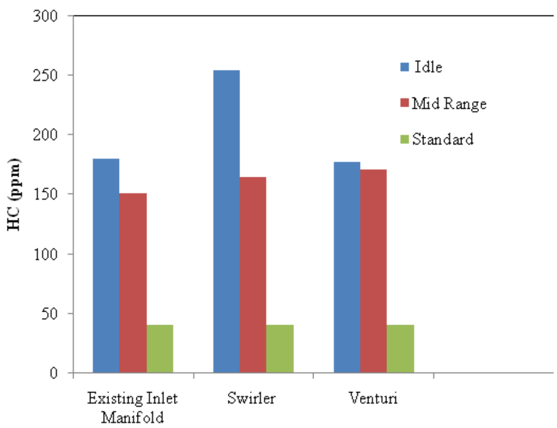

Figure 9: HC Emissions v/s Inlet Manifold Design

Figure 10: NO_x Emissions v/s Inlet Manifold Design

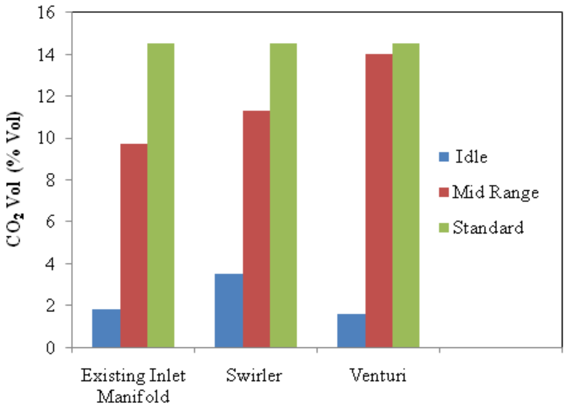

Figure 11: CO_2 Emissions v/s Inlet Manifold Design

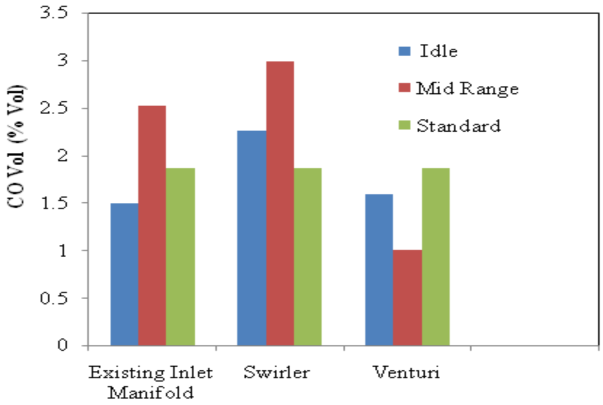

Figure 12: CO Emissions v/s Inlet Manifold Design

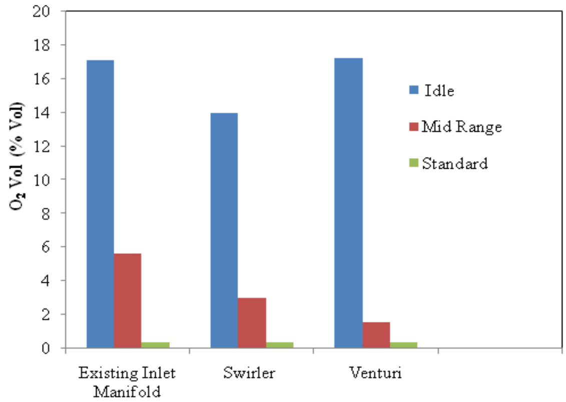

Figure 13: O_2 Emissions v/s Inlet Manifold Design

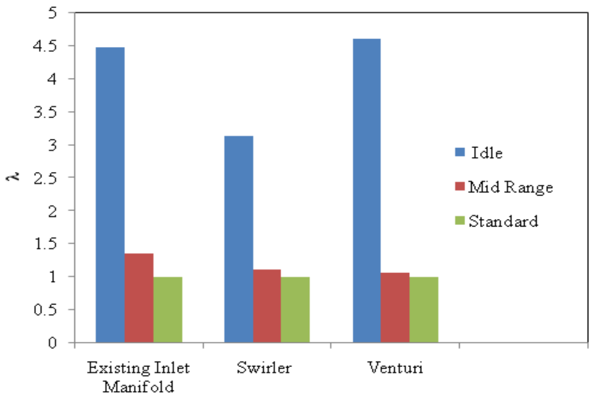

Figure 14: λ Variations v/s Inlet Manifold Design

FINAL FRAME OF INTERNAL COMBUSTION ENGINE WHICH IS SUITABLE FOR EMISSION CONTROL & PERFORMANCE PARAMETER

.

Figure 15

CONCLUSIONS

Methods exist for control of CO, HC, NO_x, CO_2 PM and PN, for stoichiometric and lean-burn gasoline engines and diesel engines. They are used and proven in many different applications. Continuous improvement in substrate and coating technologies, as part of an integrated system comprising electronic control and fuel quality, allows meeting more and more stringent combustion engines emissions legislations.

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