Analysis of Three-Way Catalytic Converter Performance with an Oxygen Sensor Using Fuel Efficiency Technique

DR. K. CHANDRASEKARAN[1], PROF. G. ABISHEK KUMAR[2], PROF. T. VAITHEESWARAN[3], DAVID PRASANTH R[4]

[1] *Professor, Department of Mechanical Engineering, M.A.M School of Engineering, Siruganur, Trichy, Tamil Nadu, India.*

[2, 3] *Assistant Professor, Department of Mechanical Engineering, M. A. M School of Engineering, Siruganur, Trichy, Tamil Nadu, India.*

[4] *UG Student, Department of Mechanical Engineering, M.A.M School of Engineering, Siruganur, Trichy, Tamil Nadu, India.*

Abstract—* Designing Automotive Oxygen Sensor for The Effective Control of NOx, HC (Hydrocarbon) and CO (Carbon Monoxide) Emissions under Both Lean and Stoichiometric Engine Operation is a Challenging Task. The Research Presented in this Thesis assesses the Performance Efficiency of a Three-Zone Prototype Catalytic Converter in Reducing Emissions from a Gasoline Engine, Operating in HCCI (Homogeneous Charge Compression Ignition) and SI (Spark Ignition) mode under Lean and Stoichiometric Conditions. The Research was carried out using Jaguar V6 engine operating in SI and HCCI mode using Commercial Unleaded Gasoline Fuel. The Oxygen Sensor Efficiency in Reducing the three Pollutant Emissions is closely related to the Exhaust Gas Conditions (e.g. Temperature and Space Velocity), Oxygen Content and Composition i.e. NO_x, CO and HC Concentrations. As Part of this Study a Quantitative and Qualitative Analysis of C1-C11 Hydrocarbon Compounds achieved before and after the Oxygen Sensor. The results show that Hydrocarbon Species formation in the Combustion Process and Destruction Over the Catalyst is Primarily Dependent on the Engine Operation and Combustion Mode (i.e. HCCI or SI). Alkane Concentrations were found to be higher in the HCCI mode, a Methane, a Naphthalene and a Methylnaphthalene were the most resistant Compounds while Toluene was the most Degradable Compound Over Catalyst.

***Index Terms-* Three Way Catalyst, Cam Profile Switching, Oxygen Sensor, Fuel Injector, Ignition Coil, ECU, HCCI.**

I. INTRODUCTION

In recent years, much attention has been focused on the engine emissions due to the stricter emission regulations worldwide and the global air pollution problems, the seek to develop more efficient but cleaner, engines are of increasing importance for automotive industries [1]. The Contribution of Exhaust Emissions reduction via sophisticated Engine System is relatively limited. The call for reduced Emission is continuing to Gain strength [2]. The Automotive Industry that the HCCI Engine is a promising concept for future Automobile Engines and Stationary Power Plants. HCCI Engines have numerous advantages Over SI and CI Engines [1]. Relative to SI Gasoline Engines, HCCI Engines are more Efficient, approaching the Efficiency of Compression Ignition Direct Injection (CIDI) Engines. Relative to CIDI Engines HCCI Engines have Substantially Lower Emissions of Particulate Matter (PM),and NOx [1]. HCCI Engines can operate using a variety of fuels such as Gasoline, Diesel, Natural Gas, Bio-fuels and Hydrogen. In HCCI Enginethe Air and Fuel are mixed together either in the Cylinder with Direct Injection or in the intake system [2].

II. OBJECTIVES

The Main Objective of this work was to study the Engine Prototype Catalytic Converter System under HCCI/SI operation and range of engine conditions [4]. Developing Hydrocarbon Speciation Methodology was another task of this work to provide information of used Fuel Components and HC Species in the Engine Out Emissions from both Engine Modes [2].
This Research Includes**:** Designing TWC Converter capable of performing under Stoichiometric andLean Engine operation to suit HCCI and SI Combustion

Modes. Investigation the performance of Proto type TWC converter based on its function of Eliminating NOx, CO, THC, and individual HC (C1-C11) from HCCI/SI Stoichiometric and HCCI Lean Operation [2].

Investigating heavy HC Species (C_5-C_{11}) from HCCI/SI Engine Technique w(GC-MS) instrumentation. Identifying the Carbonyl Compounds generated from both HCCI/SI modes andHCCI lean operation by using HPLC Technique [1]. Investigating the influence of H_2 addition on the Catalyst performance in reducing emissions under HCCI Lean Engine Operation. Providing data base with individual HC help improving HCCI Fuel components [1].

III. LITERATURE SURVEY

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IV. CATALYST DESIGNED FOR HC, CO, AND NOX EMISSIONS

4.1 EXPERIMENTAL LAYOUT AND TECHNIQUE:

: This chapter presents a study on a new catalytic converter design, which aim to control total hydrocarbon (THC), carbon monoxide (CO) and NOx emissions under lean (excess oxygen) SI/HCCI engine operation. The experiments were conducted on a Jaguar V6 gasoline engine equipped with the prototype catalyst at the one bank.The effects of engine load, speed, boost pressure and space velocity and air/fuel ratio on exhaust emissions and catalyst performance were explored. A prototype three- zone monolith catalyst as described in section was used. The THC, CO, and NOx emissions of the exhaust gases produced from HCCI/SI engine lean operation mode was carried out under different engine loads and the three different speeds upstream and downstream the catalyst. The effect of boost pressure on engine-out emissions was also investigated. The air/fuel ratio is represented by λ (1.2, 1.4, and 1.6). The experimental conditions of the V6 gasoline engine are listedin Hydrogen was added upstream of the catalyst under HCCI lean engine operation at a speed of 1500rpm to assess its ability to promote NOx reduction.

4.2 CATALYST EFFICIENCY:

Under most Engine Operation, the Prototype Catalyst covered a wide range of engine conditions. Shifting the engine operation to leaner combustion from λ=1.2 to1.6, and increasing engine load NMEP from 3 to 4.5bar respectively does not influence the engine exhaust gas temperature significantly [3]. The HC and CO conversions ranged from 90-96% over the catalyst independently from in-cylinder conditions [1]. This is the effect of interference of three parameters: retention time (space velocity), exhaust temperature, and exhaust gas composition (HC, CO, and CO_2 due to high heatcapacity) [1].

The most important factor affecting CO conversions correlated to the retention time (space velocity-engine flow rate) – the highest conversion up to 92% was achieved when engine flow rate was low in HCCI lean operation. At λ=1.2 and 2500rpm (load limited), results revealed that the highest conversion rate happened at the lowest space velocity of 24kh. Even at higher exhaust gas temperatures the increase in the engine load cannot cover the increase in the flow rate and hence, conversion efficiency is generally lower. However, the prototype catalyst has shown excellent HC and CO conversion regardless of the exhaust gas temperatures [2].

Minimal catalytic conversion of NOx emissions, up to 55% efficiency, occurred at HCCI mode, this is correlated with CO and HC emissions [1]. When CO and HC emissions are relatively low (and exhaust temperature is low) the CO oxidation deteriorates and allows higher efficiency of NO_x reduction (more CO is available for the reduction reaction). There is the possibility of a similar effect with H_2 in the exhaust gas. An optimal flow rate is required for the best NOx conversion, in this case, the most effective flow rate oscillates around space velocity of 33 kh^{-1}. Despite the catalyst lower NOx conversion efficiencies under HCCI mode, NOx emissions after the catalyst were kept at lower values compared to SI [6].

4.3 EXPERIMENTAL SET UP AND PROCEDURE:

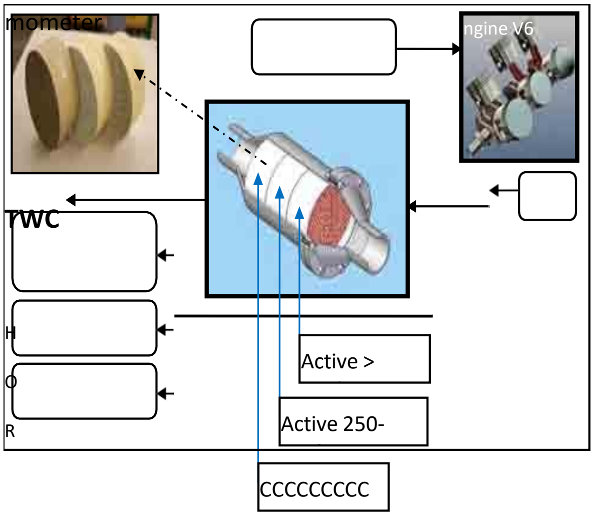


Figure 4.3.1. Schematic of Experimental Setup.

This chapter presents an overview of the research engine, prototype catalyst and detailed description of the equipments that has been used. Procedures used for data processing are also explained.

This Procedure describes a study on the performance of a three-way catalytic converter in reducing heavy hydrocarbon species in the engine exhaust under lean and stoichiometric SI and homogeneous charge compression ignition (HCCI) engine conditions. A qualitative and quantitative analysis of hydrocarbon compounds ranging from C_5-C_{11}, before and after the catalytic converter, was conducted using Gas Chromatography-Mass Spectrometry (GC-MS). Theexperimental setup for this work is shown in Figure 4.3.1. The following compounds were monitored at engine and catalyst outlet; Iso-pentane, benzene, toluene, ethyl benzene, p-xylene, iso-octane, naphthalene and methylnaphthalene.

4.4 MATERIAL USED AND FEATURE'S:

Catalyst design for HC, CO and NO_x emissions reduction in gasoline bi-mode SI/HCCI engine.

This chapter presents research on a new catalytic converter design, which aims to control HC, CO and NOx emissions under lean (excess oxygen) and stoichiometric, HCCI/SI engine operation. The experiments were conducted on a Jaguar V6 gasoline engine equipped with the prototype catalyst at the one bank from engine side. The effects of engine load speed (i.e. space velocity), air/fuel ratio, and boost pressure on exhaust emissions were studied. The influence of H2 addition upstream the catalyst on engine-out emissions produced from HCCI lean operation at 1500rpm was analysed.

Engine test conditions (3-4bar NMEP)

V. EMISSION IN GASOLINE ENGINE

Nitrogen Oxides Emissions (NO_x):

The formation of Nitric oxide (thermal) is fully explained by the mechanismproposed by Zeldovich ,Heywood.

$$O + N_2 \text{ --------------- } NO + N \text{ ----- } (1)$$

$$N + O_2 \text{ --------------- } NO + O \text{ ----- } (2)$$

Oxygen atoms are produced by the unimolecular thermal decomposition of molecular oxygen, chemical kinetics shows that NO_x increase sharply.

Hydrocarbon Emissions (HC):

Hydrocarbons escaping the combustion are quite simply, raw unburned fuel. When the engine is misfiring, there is a poor combustion occurring during the engine strokes which results in emitting a huge amount of hydrocarbon from the combustionchamber. Another source of hydrocarbon called wall quenching.

VI. EXPERIMENTAL INVESTIGATION

6.1 Three-way catalytic converter:

A prototype three-zone monolith catalyst as shown in Figure 6.1 (supplied by Johnson Matthey) was connected to the actual engine exhaust manifold. The first zone was designed to reduce HC and NOx under lean and stoichiometric engine conditions at high temperatures >400ºC, the second zone was designed to reduceNOx by reaction with HC under lean engine operation over a temperature range of 250ºC – 400ºC, while the third catalyst zone was designed to control part of the exhaust hydrocarbons and CO at temperatures below 300ºC. During preliminary testing it was observed that the middle zone catalyst was not very sensitive to thetype of hydrocarbons (e.g. chain length) in NOx reduction, while over the first zone catalyst NOx reduction activity was improved with long chain hydrocarbons. The overall dimensions of the three-zone catalyst, and hence its volume, were the same as the production three-way catalyst with which the engine was originally equipped.

Figure 6.1. Prototype three-zone monolith

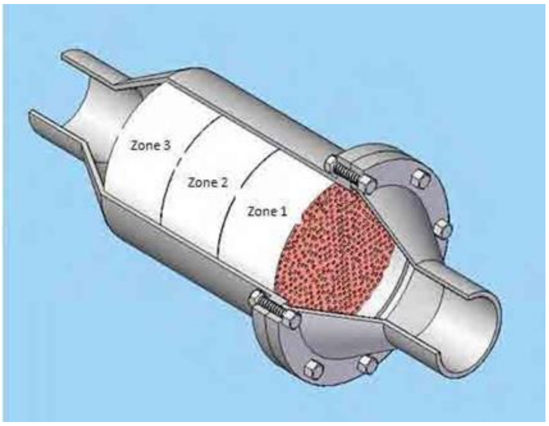


Figure 6.2. Prototype Catalyst After treatment - 3 Zones

Engine Condition			Engine Mode	Engine Emissions			
Conditions	λ	NMEP (bar)		HC (C1 ppm)	CO (%)	NOx (ppm)	O2 (%)
1	1	3.0	HCCI	3065	0.56	12	1.2
2	1	4.0	HCCI	2196	0.63	104	1.2
3	1.4	3.5	HCCI	2622	0.09	12	6.29
4	1.4	4.5	HCCI	2106	0.08	43	6.55

Table (6.1)

Catalyst efficiency from optimised catalyst arrangements (HCCI modes and SI mode) and fuel consumption at an Engine Speed of 2000rpm

Engine Condition				Catalyst Conversions (%)			Fuel Cons g/hr	$T_{Ex.}$ °C
Cond.	λ	Mode	NMEP (bar)	NS HC	NS CO	NS NOx		
1	1	HCCI	3.0	60	91	30	3000	385
2	1.4	HCCI	3.5	96	88	40	3900	349
3	1	SI	4.0	95	100	94	5200	661
4	1.4	HCCI+ H_2	4.5	91	87	40	4800	406

Table (6.2)

NS= Nett (indicated) specific NMEP=Nett Mean Effective Pressure

Catalyst performance with H_2= 2400ppm addition upstream thecatalyst, HCCI operation of engine load 3bar, λ = 1.2, 1.4, 1.6

Hydrogen addition upstream of the catalyst has strongly affected NOx conversion in HCCI lean operation, as seen in Figure 4.10. The NOx conversion is highly dependent on the reaction temperature and gas composition (e.g NOx and HC concentrations in the exhaust). Regarding the NOx conversion without H_2 addition (2400ppm) at HCCI when the flame propagation front burns close to the cool walls of the combustion chamber. Emissions under HCCI and SI modes at enginespeed 2000 rpm.

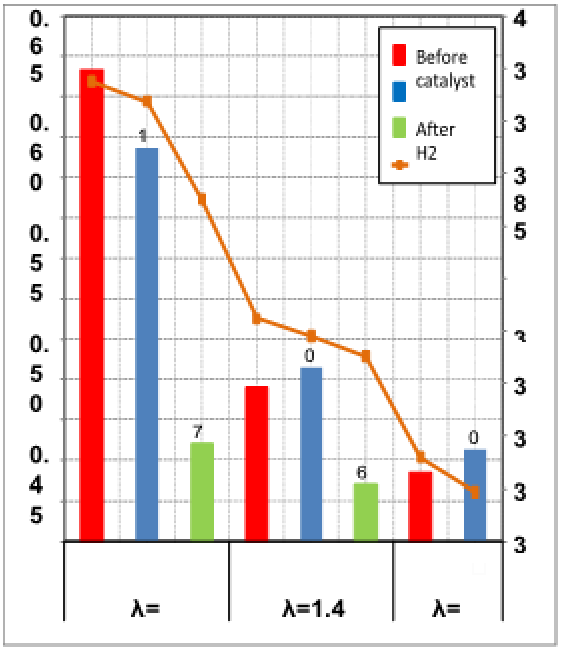
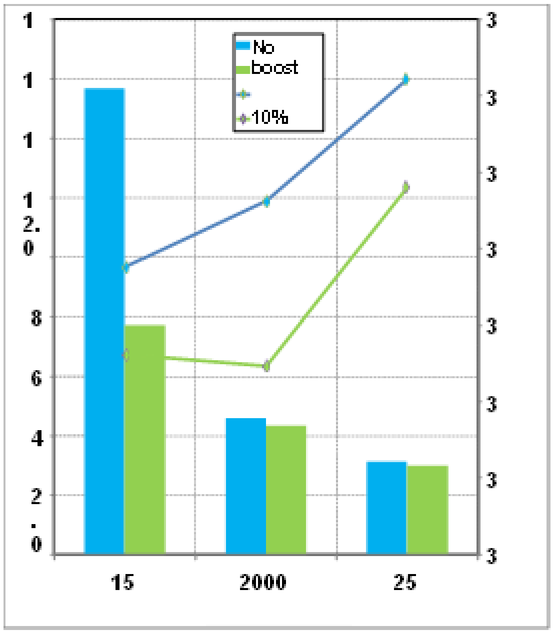


Chart (6.1): HC conversion efficiency over catalyst with H_2 addition (3barNMEP), HCCI lean operation, engine speed 1500rpm.



Engine spped (rpm)

Figure 6.3: HC emissions at different engine speeds with no boost pressure and with 10% boost pressure(5bar NMEP)

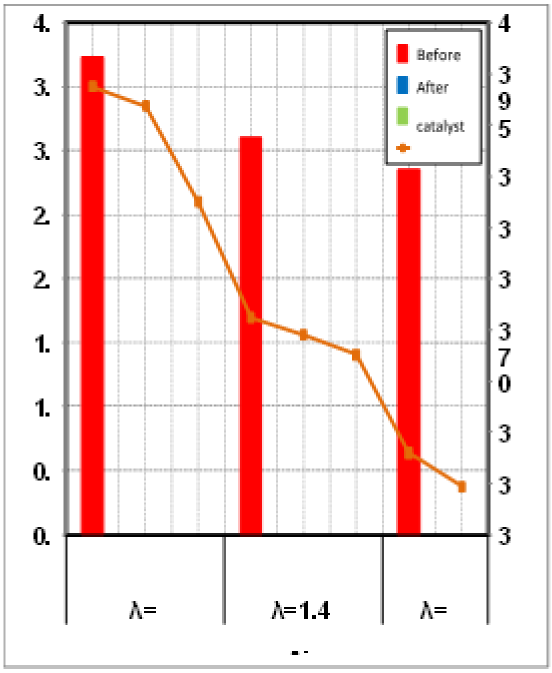
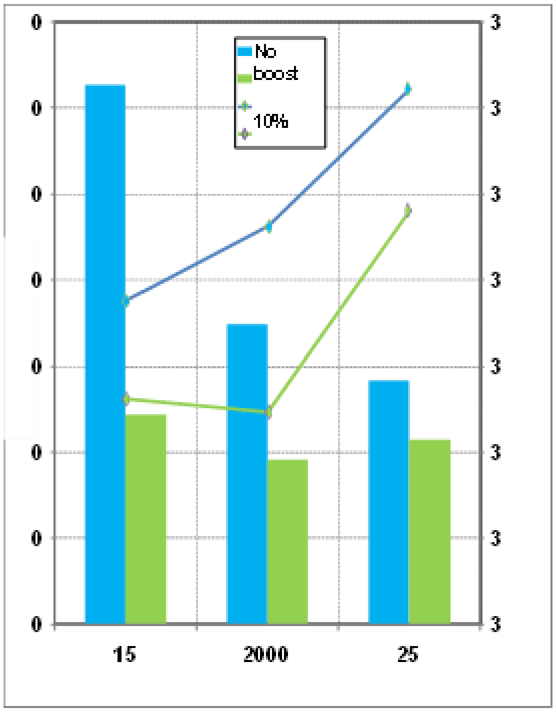


Chart (6.2): CO conversion efficiency over catalyst with H_2 addition (3barNMEP), HCCI lean operation, engine speed 1500rpm.



Engine spped (rpm)

Figure 6.4: CO emissions at different engine speeds with no boost pressure and with10% boost pressure (5bar N

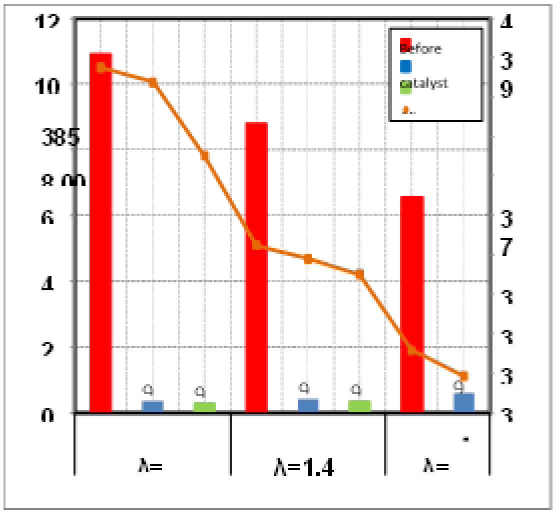
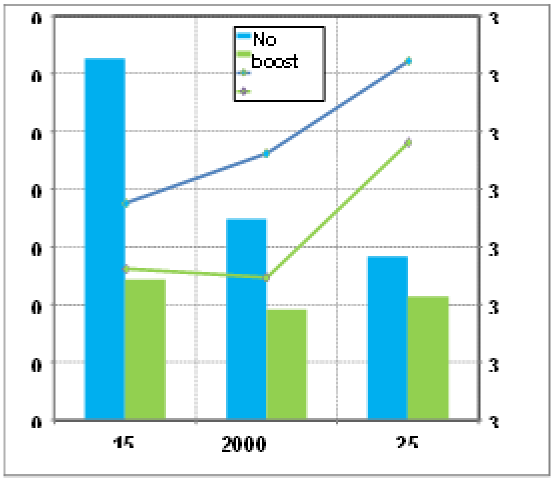


Chart (6.3) : NOx conversion efficiency over catalyst with H_2 addition (3barNMEP), HCCI lean operation, engine speed 1500rpm



Engine spped (rpm)

Figure 6.5 : NOx emissions at different engine speeds with no boost pressure andwith 10% boost pressure (5bar NMEP)

VII. RESULT AND DISCUSSION

An important study of HCCI/SI combustion technology could be essential to gain more understanding of the emissions reduction possibility via different combustion conditions such as changing the compression ratio or ignition timing etc. Emissions of some potentially important pollutants such as carbonyls (especially carbonyls other than formaldehyde and acetaldehyde) have not been thoroughly investigated for pure fuels such as ethanol, methanol or other fuels.

Diesel and gasoline could be mixed to form different fuel blend which could be analysed from HCCI engine-out emissions and downstream the converter.

Further speciation of the HCCI exhaust hydrocarbons is needed, by using a new set of known polycyclic aromatic hydrocarbons to study the relationship between amount, type, and carcinogenic potency of polycyclic aromatic hydrocarbons in HCCI engine emission and the fuel composition.

The investigation of carbonyls in the exhaust of HCCI combustion should be extended to oxygenate and alcohols fuel, to bring a clear picture and gather comprehensive data about oxygenated hydrocarbons produced in HCCI engine mode.

CONCLUSION

As seen from the previous chapters, the combustion mode has a strong effect on hydrocarbon species from HCCI/SI combustion. Most of the unsaturated species (e.g.ethylene, propylene) are combustion products of the SI mode, while saturated species(e.g. methane, iso-octane) are combustion products of HCCI mode. On the other hand some aromatic species (e.g. benzene, toluene) escaped the combustion process in both engine modes. In addition with HCCI combustion a lot of low temperature reactions take place producing intermediate products, which make it difficult to understand the formation of chemical species in the HCCI mode. This work main contribution will be summarised in this chapter and the suggested future work will follow.

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