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OBD-II and Catalytic Converter to Maintain Low - Emission from I.C. Engine in India

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Abstract: - We know that catalytic converter is converting harmful gases to harmless gases. Due to the engine combustion process the catalyst encourages two chemical to reach with each other and for example, Hydrocarbon (HC) and Carbon monoxide (CO) and Carbon di-Oxide (CO^2) and the catalyst in the NOx converter splits the Nitrogen from the Oxygen.

OBD-II, systems were designed to maintain low emissions of in use vehicles, including light and medium duty vehicles. In 1989, the California code of Regulations (CCR) known as OBD – II was adopted by the California Air Resource Board (CARB) and the objective to reduce hydrocarbon (HC) emission caused by malfunction of the vehicles emission control systems.

As per Environment Protection Agency, (EPA) USA, and CARB standards the failure criteria for the catalyst monitor diagnostic are the following:

- MY 96: xLEV's: converter efficiency: HC converter efficiency $<$ 50 – 60 % on FTP Test.
- EPA MY 98: HC: exceeding 0.6 g/m or increase by 0.4 g/m over the 4000 m value.
- Catalyst heating system: Pre-start heater: attained designed temperature- after- start- heater : Exceeding any of the applicable , FTP standard x 1.5.

It is an important system for diagnostic. The inputs to Enable Catalyst Monitor are: Engine air flow, closed loop stochastic state, coolant temperature, vehicle speed, engine air load, engine speed, throttle position, decal fuel cut of, fuel control requested , fuel control ready , intake air temperature an fault active start. This process determines if the catalyst monitoring is required for steady state condition or for FTP based conditions. Depending on this choice the appropriate catalyst temperature prediction model is used for the diagnostic test.

Keywords: Catalytic Converter, Catalyst heating system, Catheat ,Enable Catalyst Monitor, Engine Air Flow, GBD (Gap Bulk Density), Heatcard, P-cat, Secondary Air, Throttle Position, Platinum and rhodium.

1. INTRODUCTION:

Catalytic converter is converting harmful gases to harmless gases. It is a muffler like device for use in an exhaust system. A catalyst is a material that causes a chemical change without entering into chemical reaction.

Due to the combustion process the catalyst encourages two chemicals to reach with each other. For the example, Hydrocarbon (HC); Carbon Monoxide (co) and Carbon die-oxide (CO2). The catalyst in the NOx converter splits the Nitrogen from the oxygen.mFor the controlling Oxides of Nitrogen (NOx) rhodium is used as a reducing catalyst. It changes NOx to harmless N2. For the dual bed catalytic converter, having two separate catalytic converters, in the exhaust system.Instead of having two separate catalytic converters in the exhaust system i.e. one for Hydrocarbon (HC) and Carbon Mono-Oxide (CO) and the other for Oxides of Nitrogen (NOx).

Computer aided engineering is used to design, development and manufacture catalytic converter. Heat cad, transient heat analysis is used to simulate the temperature response in the exhaust system to locate the catalytic converter to achieve maximum performance. Durable catalytic converter mounting, using then wall substrates, poses the challenge of developing new converter canning techniques. Conventional catalytic converter development driven by trial and error attempts by experts who successfully employ heuristics (a set of empirical rules gained through time and experience) will not be able to meet the current demanding needs. The cost and time involved in testing every catalytic converter mandates new approaches aimed at improving efficiency and reducing development lead time. Computational modeling and engineering using Heat card , P-cat, Cat-head, WAVE, CFD, FEA and Monte- carol simulation provides major in roads to design , develop, optimize and manufacture catalytic converter.

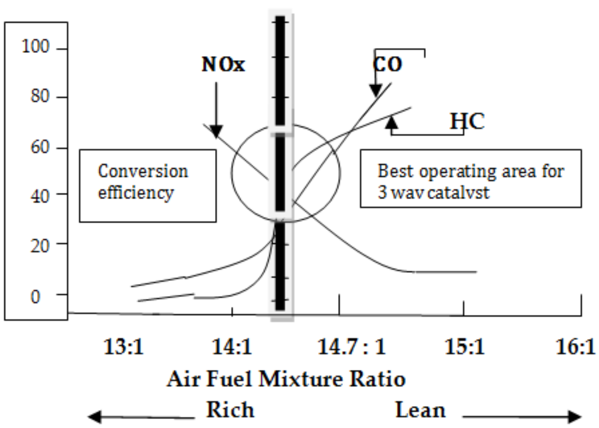

Fig: 1.a. Air Fuel mixture ratio "window" within which the air fuel ratio must remain if the three way catalyst is to work.

2. Literature Review:

Most manufactures use the following catalytic converter:

2.1. Dual bed Catalytic Converter,
2.2. Three ways catalytic converter.

Dual bed catalytic Converter is like two bed-type converters in one housing with an air chambr between them. The exhaust gas first passes through the upper bed, reducing the NOx and oxidizing some of the HC and CO respectively.

Three way catalytic converter is a mixture of platinum and rhodium. It acts on all three of the regulated pollutants (HC, CO and NOx), however, the only air-fuel mixture is precisely controlled . For example, if the engine is operated with the ideal or stoichiometric air fuel ratio of 14.7: 1, the three way catalyst is very effective.

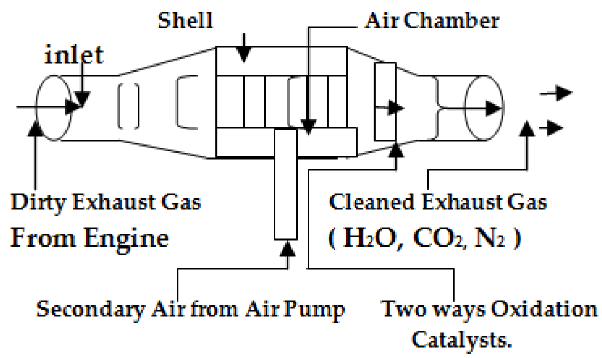

Fig: 2.a. A Three ways Catalytic Converter

As India prepare to make the use of catalytic Converter Compulsory towards the drastrically reduceing automobile exhaust emission and this regard Environmental Protection Agency (EPA) in USA has observed that the catalytic converter has became a siginificant and growing cause of global warming.

However, Converter canning process simulation process has substantial impact on the quality and performance of the converter, since the pressure distribution on the substrate, the GBD (Gap Bulk Density) distribution in the mounting mats are affected by the converter shell design, canning tool design as well as the closing speed and load.

3. Methodology:

There are two types of three way catalytic converters. The front section handles Oxides of Nitrogen (NOx) and partially handled HC and CO . The partly treated exhaust gas then converter. There the gas mixes with the air being pumped by the air pump. This is called Secondary Air.

3.1 Diagnostics Appraches:

As per Environment Protection Agency, (EPA) USA, and CARB standards the failure criteria for the catalyst monitor diagnostic are the following:

3.1.1. MY 96: xLEV's: converter efficiency: HC converter efficiency $<$ 50 – 60 % on FTP Test.
3.1.2. EPA MY 98: HC: exceeding 0.6 g/m or increase by 0.4 g/m over the 4000 m value.

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3.1.3. Catalyst heating system: Pre-start heater: attained designed temperature- after- start- heater: Exceeding any of the applicable, FTP standards x 1.5.

The front catalyst may be monitoried in combination with the next down stream catalyst if malfunctioning will be indicated when the front catalyst alone malfunctioning. It the front catalyst is a "small volume catalyst", the next catalyst down stream must be monitoried.

Each monitored catalyst is considered malfunctioning when FTP HC efficiency falls below 50% to 60%. If the front catalyst is monitored in combination with a down stream catalyst, the front catalyst is malfunctioning when the FTP HC effecting is $\leq$ 40 % to 50% from its 4000 mile value.
Normally the oxygen capacity of the catalyst deteriuous very fast due to the high temperatures.

3.2. Catalyst Monitor Disgnositc System: Enable Catalyst Monitor :(Enable Catalyst Monitor function is consisting by :

3.2.1. Check warmed up status:

Tha above test which is performed for steady catalyst monitoring and the following catalyst warm up:

3.2.1.1. The engine is running in closed loop and at a stoichiometric air/imifuel value to maximum catalyst efficiency. (Stoichiometric ratio means, it is spark ignition engine, the idle air-fuel mixture ratio of 14.7:1, which must be maintained on engine with duel-bed and three way catalytic converter).

3.2.1.2. The coolant temperature is greater than a minimum warmed up steady state value. (Cooling system that removes heat from the engine by the circulation of a collant, for example, in he jackets of liquid-cooled piston engines or as a film on the inner wall surfaces of combustion chambers).

3.2.1.3. A minimum airflow greater than calibrated air flow threshold and a minimum engine speed greater than calibrated engine speed threshold are existing. Etc.

All the above enable criteria are met then the catalyst is considered to be warming up.If any criteria are not met the catalyst is considered to be cooling down and the down time is also counted. Heat distribution in a given engine will give sufficient indication as to how efficiently the engine is working and the general distribution of heat in an I.C. Engine is shown below:

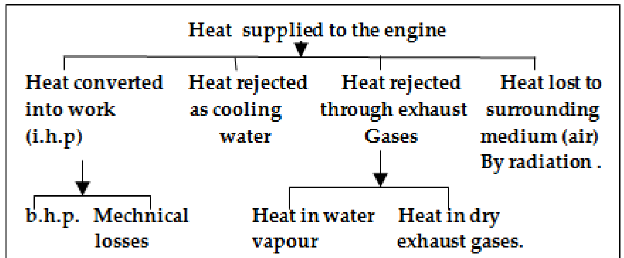

Fig. Table No. 1.

For example, a 4 cylinder automobile engine of bore 85.7 mm and stroke 82.5 mm with a cpmpression ratio of 7:1 was tested on a dynameter which has an arm of 533.5 mm long. The dynamometer scale reading was 40.8 kg and the speed of the engine 4000 rpm. During the 10 minutes run fuel consumption was 4.55 kg. The calorific value of the fuel was 11000 kcal/kg. Quantity of air supplied through the MPFI/Carburettor was 5.44 kg/min at a pressure of 1.027 kg/cm2 and a temperature of 21^{0} C . The find out the following:

(a) Brake Thermal Efficiency.
(b) Volumetric Efficiency.

$$\text{Brake Thermal Efficiency} = \frac{\text{b.h.p x 4500}}{\text{(wf x C.V.) x J}} \times 100$$

$$= \frac{4500 \text{ x } 121.1}{0.455 \text{ x } 11\ \text{ooo x } 427} \times 100$$

$$= 25.6\%$$

$$\text{Volumetric Efficiency} = \frac{\text{volume of air actually sucked stroke}}{\text{Swept volume}} \times 100$$

$$= \text{Volume of air actually sucked per cycle}$$

$$= \frac{5.44 \text{ x } 29.27 \text{ x } 294}{2000 \text{ x } 1.027 \text{ x } (10)\,4} \times m^3$$

$$\therefore \mu_0 = \frac{5{\cdot}44 \times 29.27 \times 294 \times 4 \times 10\ (6)}{8 \times 2000 \times 1.027 \times (10)4 \times \pi \times (8.57)^2 \times 8.25} \times 100$$

$$= 60\%$$

3.3.1.Time for catalyst to warm up:

This test is performed for steady state catalyst monitoring , the following:

3.3.1.1.The engine is running in closed loop and at a stoichiometric air fuel mixture value to maximize catalytic efficiency. For example.

Normal Mixture: One kg of gasoline mixed with 15 kgs of air, is called Normal Mixture.

Lean Mixture : Need of air is more than 10% in the mixture is called Lean Mixture.

Rich Mixture: if one part of gasoline is mixed with 12 or 15 parts of air , i.e. ratio is 10:12 is called Rich Mixture.

3.3.1.2. Coolant temperature is greater than a Minimum warmed up steady state value. A minimum air flow is

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greater than calibrated air flow threshold and a minimum engine speed greater than calibrated engine speed threshold are existing. Etc. If all of the above enable criteria are met then the catalyst is considered to be warming up and tha said criteria is not met the catalyst is considered to be cooling down and the cool down time is also counted and this timer serves for the catalyst temperature. If warm up criteria is greater than a calibrated time than the catalyst is considered warm enough to conduct the diagnostic test.

3.3.3 Generate delta engine load :

The main objective of this function is calculating the engine air load delta , which is the magnitude of difference between the engine load data and its weighted average engine load value and this procedure for disabled during transient engine liading diagnostic.

3.3.4. Monitor test disable conditions:

The said function, the status of all Type A and Type B active faults including misfire but excluding catalyst faults that could influnce the result of the catalyst test and this active fault status is true then this function disables the current test for the reminder of the current trip.

4. RESULT AND DISCUSSION:

(Predict catalyst temperature)

This function is performed only FTP – based catalyst monitoring and predicts the catalyst bed temperature as a linear function of engine speed and engine air flow and the following polynomial equation:

Catalyst temperature = Engine speed

(*Engine speed coefficient + Engine air flow;* *Engine air flow coefficient + Offset*)

For example: The following observations were obtained during a trial of an I.C. Engine.

1. Fuel used : 5.5 Litre/hr,
2. Calorific value of the fuel : 10500 kcal/Litre,
3. I.H.P. : 25,
4. Cooling water used : 12 Litre/min,
5. Temperature rise of cooling water : 30° C,
6. Temperature rise of 10 Litre water by Exhaust gases per min : 30° C

Calculate Indicated thermal and draw heat balance sheet for he engine:

Solution:

Heat supplied by the fuel per min

$$= \frac{5.5}{60} \times 10500$$

$$= 963 \text{ kcal.}$$

$$\text{Indicated thermal } \mu = \frac{\text{i.h.p} \times 4500}{(\text{wf} \times \text{C.V.}) \times \text{J}} \times 100$$

$$= \frac{25 \times 4500}{\left(\frac{5.5}{60}\right) 10500 \times 427}$$

$$= \frac{60 \times 25 \times 4500}{5.5 \times 10500 \times 427} \times 100$$

$$= 27.4\ \%$$

$$\text{Heat ti i.h.p.} = \frac{\text{i.hp.} \times 4500}{\text{J}}$$

$$= \frac{25 \times 4500}{427}$$

$$= 264 \text{ kcal}$$

$$\text{Heat to cooling water} = 12 \times 30$$

$$= 360 \text{ kcal}$$

Heat carried away by exhaust gases

$$= 10 \times 30$$

$$= 300 \text{ kcal}$$

Heat Balance Sheet		
Item	Heat units(kcal)	percent
Heat supplied to fuel	963	100%
Heat to i.h.p.	264	27.41%
Heat to cooling water	360	37.40%
Heat to exhaust gases	300	31.14%
Heat unaccounted for (by difference)	39	4.05%
Total	963	100%

Table No.2 : Heat Balance Sheet

The steady state catalyst tempeture defaults to a minimum calibrated value when a decal fuel cut off or open loop condition is present or when the engine coolant is not warm enough to enable the model. The mximum steady state temperature is limited by placing upper limits on engine speed and engine air flow as well as an overall maximum limit on the calculated steady state value.

The predicited catalyst temperature is a low-pass filtered version of the predicted steady state catalyst temperature. A separate filter coefficient exist for increasing temperature versus another filter coefficeient for deceasing temperatures . If the engine is running and the predicted catalyst temperature is greater than or equal to

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the calibrated minimum warmed up temperature , the catalyst is considered warm enough to test its oxygen storage capacity.

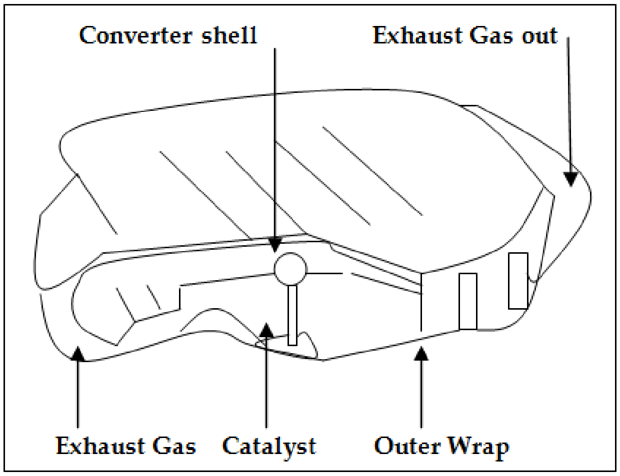

Fig: 4(a) Oxodizing Catalytic Converter

Check the limit conditions, this function determines if the engine is satisfying the following higher level enable criteria for performing a catalyst efficeiency monitor test.

The catalyst temperature is hot enough to conduct the catalyst monitor diagnostic and the exhaust system warmed up status is set to true.

There are no conditions that disable the test for the rest of the trip coolant temperature is greater than calibrated threshold . Engine air flow within calibrated threshold window limits . The engine Air Fuel control is closed loop and commanding stoichometry . The delta
Engine load is less than calibrated threshold and engine air load is less than calibrated threshold. The ngine speed is less than calibrated threshold along with vehicle speed is less than calibrated threshold.

The over and above, the catalyst monitor test has not run this key on:
If any of the above , enable criteria are not meet then the high level catalyst efficiency monitor enable state is est to false and no request is made for conducting the diagnostic test any further and no request is made for an alternative catalyst fuel control mode for conducting the intrusive test which will be called off.

5. TYPE OF DATA:

The four basic canning and Gap Bulk Density (GBD) control methods used in ceramic converters are summarized. Hot rolled , stuffed-sized and swigged are derivatives of the stuffed design process.

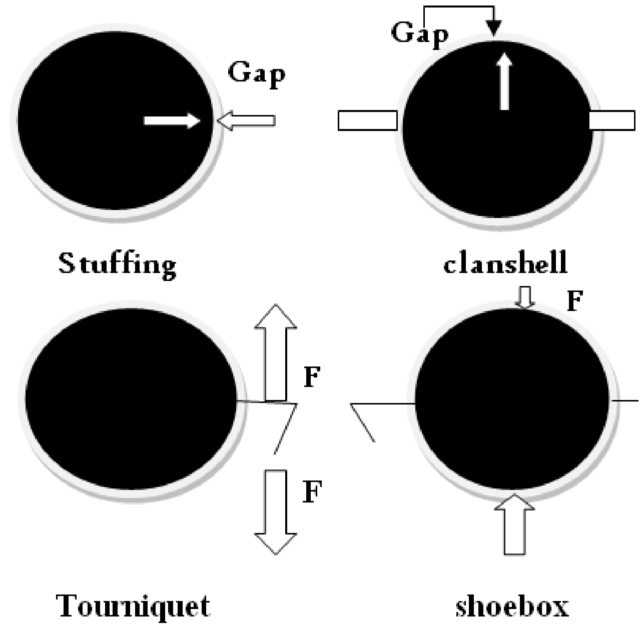

Fig:5(a) Four Basic canning Methods.

Closing the can using fixed Gap has the advantage of offering a fixed dimension of the converter, which simplified the design and welding of the cones and shells. Closing the can using fixed force has the advantage of offering influence of the shell, mat and substracte dimensions.

The single seam or single shell design is usually preferred for round , trapezoidal or oval converters with low aspect ratios because it offers the most uniform GBD distribution. Moreover , using a single rolled and cut shell provides greater manufacturing flexibility , allowing fast design changes without the need of expensive stamping tool modifications.
Gap Bulk Density (GBD) is defined as the density of the mounting mat in the gap between the substrate and converter shell.

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$$GBD = \frac{\text{Mat Basis Weight}}{\text{Gap}} \quad \text{--------} \ (1)$$

For Found Converters ,

$$Gap = \frac{\text{I.D.shell} - \text{O.D.Substrate}}{2} \Big| \quad \text{--------} \ (2)$$

A real converter has an infinite number of GBD.s equations 1 and 2 for round converter can be summarized as follows:

$$\text{Average GBD} = \frac{2}{n}\sum_{i-1}^{n} \frac{\text{Mat basis weight}}{\text{I.D.Shell} - \text{O.D.Substrate}} \quad \text{----}(3)$$

6.
7.

The above equation states that the substrate has an average GAP around the whole circumference and shows that GBD is affected by the MAT weight, shell diameter and substrate diameter. Any uncertainly on the value of these parameters affects the final GBD value. Therefore, GBD depends on the manufacturing tolerance of the MAT, shell and Substrate.

The MAT specification targets is correct and assuming that the manufacturing processes are under control. It is conclude that the target of GBD = 1.00 g/cm3 is temperature/vibration or cold failure conditions this target might not be acceptable.

Control Parameters	Single seam	Split Shell
Fixed Gap	Stuffing	Clamshell
Fixed Force	Tourniquet	Shoebox

TableNo. 3: Four Basic GBD Control Methods

From the above, the following summary:

1. Heatcard analysis is used to design an optimize the manifold of the exhaust system and to locate the catalytic converter at the right place for maximum light – off performance.
2. P-cat is used to optimize the substrate size, cell density and wall thickness of the catalytic converter with minimum back pressure. 8. 9. 10.
3. Catheat is used to identify the mounting mat to meet the required external skin temperature.
4. CFD is used to design to downpipes and the converter for the designed uniformity index, encentricity index and pressure index. 11. 12. 13.

6. CONCLUSION or MAIN FUNDING:

5. Secondary Air System Monitoring system is used to improve the performance of the catalytic converter (Three way) by providing extra oxygen rich air o either the converter itself ot to the exhaust manifold. The catalyst temperature must be above about 200° C to efficiently oxidize HC and reduce NOx. Durng engine warm up when the catalytic converter is cold , HC and CO are oxidized in the exhaust manifold by routing secondary air to the exhaust manifold in controlled quantify by the PCM.

During the open loop control the converter is liable to bedamaged if excessive heat is applied to it, to warm it up. This can happen if excessive amounts HC and CO are oxidized in the exhaust manifold during periods of heavy load which call fr fuel enrichment or during severe decleration. During start up and such

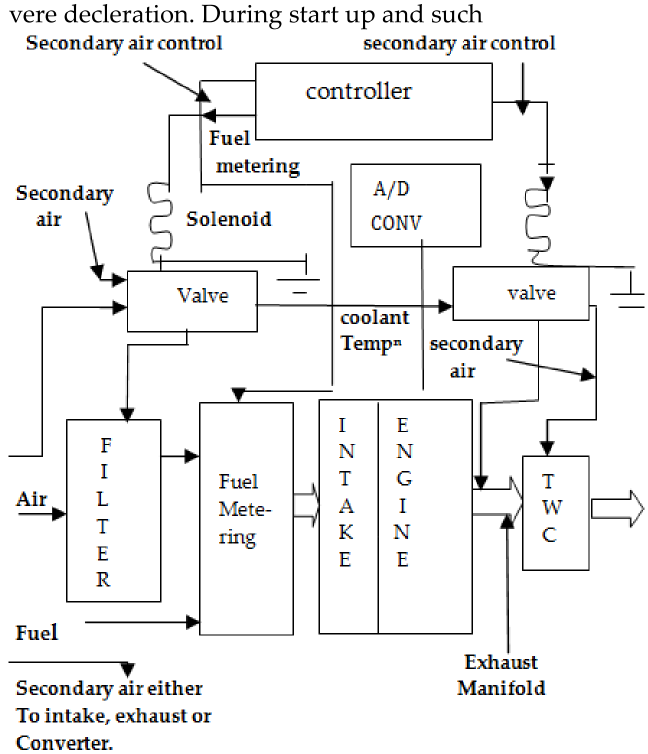

Fig: 6(a) Foundamental Powertrain (Secondary Air)

heavy load, the secondary air is not let into exhaust manifold but directed into the air cleaner where it has no effect on exhaust temperature.

After warm up, during closed loop operation, the secondary air is used to supply oxygen to the secondchamber of the three way catalyst, in dual chamber converter system. In a dual chamber converter , the first chamber chamber contains rhodium, palladium and platinum to reduce NOX and to oxidize HC and CO. The second chamber contains only platinum and palladium. The extra oxygen from the secondary air improves the converters ability to oxidize HC and CO in the second converter chamber. The control of the secondary air is done by using two solenoid valves similar to the EGR pintle valve. One valve switches air flow to the exhaust manifold or to the air cleaner. The other valve switches air flow to the exhaust manifold or to the catalytic converter. The ai routing is controlled based on engine coolant temperature and air fuel ratio , indicated by the lambda sensor. If the control is open-loop and if the coolant temperature is below threshold and Air Fuel Ratio is not too rich , then the air flow is directed to the air cleaner which exits to the atmoshphere. If the control is closed – loop , then the lambda sensor is monitored for correlated deviations when the secondary air flow is changed from exhaust manifold or catalytic converter or air ceaner , depending on coolant temperature and lambda value.

For example,

The air at a temperature of 15°C enters the compressor of a turbine unit and is compressed to four times the initial pressure , with an adiabatic efficiency of 85% . The air is then passed through heat exchanger of 80% efficiency and is heated by turbine exhaust gases before reaching the combustion chamber. The maximum temperature after constant pressure combustion is 5 ° C and the adiabatic efficiency of the turbine is 76%. Neglecting all losses find the efficiency of the cycle.

Solution:

$T_1 = 273 + 15 = 288° K,$

$P_2 = 4P_1$

$r = \left(\frac{P2}{P1}\right) = 4$

$T_2' = 288 \times (4)^{\frac{0.4}{1.4}} = 428° C$

$T_2 - T_1 = \frac{T2' - T1}{\text{compressor efficiency}}$

$= \frac{(228-288)}{0.85} = \frac{140}{0.85}$

T_4 = Temperture of the gases entering the Turbine.

$= 590 + 273 = 863°K$

$\therefore T_5' = \frac{863}{(4)^{\frac{0.4}{1.4}}} = 581\ °K,$

Also, $\frac{T4-T5}{T4-T2}$ = Adiabatic efficiency of the Turbine

$= 0.76$

$\therefore \quad = 0.76 \frac{863-T5}{863-581}$

$\therefore T_5 = 648.8$ K,

Efficiency of the heat exchanger $= \frac{T3-T2}{T5-T2}$

$= \frac{\text{Heat changed}}{\text{Heat available for exchange above T2}}$

Where, T_3 = Temperature of the air leaving the heat exchanger.

$\therefore 0.8 = \frac{T2-452.8}{648.8-452.8} = \frac{T2-452.8}{196},$

$\therefore T_3 = 196 + 0.8 \times 452.8 = 648.8°$ K,

$\therefore$ Heat supplied per kg of air $= C_p\ (T_4 - T_3)$

$= 0.24\ (863 - 648.8) = 51.5$ kcal.

Compressor work per kg of air $= Cp\ (T_2 - T_1)$

$= 0.24\ (452.8 - 288) = 39.58$ kcal,

Turbine work per kg of gases $= C_p\ (T_4 - T_5)$

$= 0.24\ (863 - 648.8)$

$= 41.4$ kcal.

Net out put $= 51.4 - 39.58$

$= 11.82$ kcal/kg

$\therefore$ plant efficiency : $\frac{11.82}{51.5} \times 100$

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8. Definition/Acronyms/Abbreviation

Definition:

Air Injector: This system of injecting fuel, into the combustion chamber of a diesel engine using a blast of compressed air.

Catalyst: It is a substance which either speeds up or slows down the reaction between two other substance . But it, itself is not consumed in the process.

Pintle: A small extension of the needle valve tip projecting through the discharge nozzle. When the needle lifts, the oil passes through the opening between the circumstance of the orifice and that of the pintle.

Secondary Air: air that is to thermal reactors, catalytic converters , exhaust manifold or cylinder head exhaust ports promote the chemical reaction that reduce exhaust gas pollution.

Acronyms

Idle Air Control valve (IACV): The valve is an electronically controlled throttle by pass valve which allows air to flow around throttle plate (which is closed due to low engine rpm and vehicle being stationery) and produces the same effect as if the throttle slightly opened.

Lean Mixture: A mixture having proportion of air to fuel more than that theoretically necessary for complete combustion.

Rich Mixture: It is used to express a petrol /air mixture that has an excess of fuel.

Solenoid: A type of electro-magnet often used to operate the starter motor switch.

Abbreviation

CARB = California Air Resource Board.
CCR = California Code of Regulations.
DTC = Diagnostic Trouble Code,
FTP = Federal test Procedure.
I.C. ENGINE = Internal Combustion Engine.
IACV = Idle Air Control Valve.
MIL = Malfunction Indicator Light.
MAP = Manifold Air Pressure
PCM = Powertrain Control Mode.
SCR = Selective Catalyst Reduction.