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Design Development and Analysis of Exhaust Gas Recirculation System for CNG Fuelled SI Engine

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Abstract : Worldwide emission regulation has been tightening year after year. There is a need to work out combinations of key technologies to meet the forth-coming emission norms. Exhaust Gas Recirculation (EGR) System is one such technique that uses the Exhaust Gas coming from Exhaust Manifold to Inlet Manifold in order to reduce the Emission of NO_x, which is particularly very harmful. Engine without EGR are more pollutant & uses more atmospherically air for combustion. By Implementation of EGR system in Engine, the Partial Exhaust Gas is re-circulated again in Engine. It is first cooled in EGR Cooler & then it is mixed with atmospheric air & then passed to Combustion Chamber. Fresh atmospheric air required is reduced & automatically pollutant (NO_x etc.) is reduced. Experiments were carried out on computerized three cylinder four-stroke petrol engine (27.6 kW@ 5000 rpm). Exhaust gas recirculation set-up is developed. Engine was tested with different EGR percentage. i.e. 0 %, 5 %, 10 % & 15%. Effect of EGR on CO, CO_2, NO_x and other performance parameters like brake thermal efficiency, specific fuel consumption were studied. There is considerable reduction in oxides of nitrogen (NO_x). The system is very much Eco Friendly. Using Exhaust Gas Recirculation (EGR) Technique in engines, the emissions are very much controlled.

Keywords— *NO_x, EGR, CNG, Gasoline*

I. Introduction

Internal combustion engines, being the major power source in the transportation sector play an important role in the man-made emissions. While the mobility in the world is growing, it is important to reduce the emissions that result from transportation. The internal combustion engines in cars, trucks and other vehicles produce several kinds of emissions like CO, CO_2, NO_X etc. These emissions play a significant role in global warming. Reducing emissions has become one of the most important goals faced by automotive engineers.

Like carbon dioxide, nitrous oxide is a greenhouse gas. This means that it traps the heat in solar radiation sunlight within our atmosphere and uses it to heat the Earth's surface. Without the heat trapped by greenhouse gases, the surface of the earth would be too cold to support life. However, the right balance is important. While too little would turn the earth into a frozen snowball, too much would turn it into a sweltering jungle or desert. Human beings and our technology have evolved to require a certain climate. Anything that changes that climate may affect the way we live, dramatically altering agricultural patterns and melting the polar icecaps. It's clear that reducing nitrous oxide emissions from cars is just as important as reducing carbon emissions, Hence, in order to meet the environmental legislations, it is highly desirable to reduce the amount of NO_x in the exhaust gas. Nitrous oxide is produced at very high temperatures, so anything that lowers the operating temperature of an internal combustion engine would reduce NO_x emissions.

CNG is a fossil fuel substitute for gasoline (petrol), diesel, or propane/LPG. Although its combustion does produce greenhouse gases, it is a more environmentally clean alternative to those fuels. CNG is used in traditional gasoline internal combustion engine cars that have been converted into bi-fuel vehicles (gasoline/CNG). CNG emits significantly less pollutants such as carbon dioxide (CO_2), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x) and particulate matter (PM), compared to petrol. Due to lower carbon dioxide and nitrogen oxides emissions, switching to CNG can help mitigate greenhouse gas emissions.

PROPERTIES OF CNG

- Octane number: Octane number is the indication of the resistance of the fuel to the combustion knocking. Higher the octane number higher is the compression knock resistive in the IC engine [1]. As CNG has octane number more than 120, makes the engine operation possible at higher compression ratio. The thermal efficiency of Otto cycle based engine increases with increase in compression ratio.

- Ignition energy**:** Ignition is the minimum energy required to ignite the air-fuel mixture within flammable limit. The ignition energy is important from the flame initiation point of view during combustion process [2]. Higher ignition energy of CNG needs the high energy ignition system for CNG fuelled engine. It is important to note that the higher ignition energy makes the CNG more safer fuel in case of any leakage.
- Auto-ignition Temperature: Auto ignition temperature is the minimum temperature of the air fuel mixture required to initiate combustion in the absence of any ignition source. It is useful to avoid the pre-ignition of the air-fuel mixture ahead of the flame front [3]. Higher ignition temperature of the CNG makes less chance of ignition due to contact with hot surfaces. Hence CNG is safer.
- Emission: The carbon based emissions are directly proportional to the C/H ratio of the fuel. The fuel with less C/H ratio like CH_4, H_2 etc has advantage in term of carbon based emission. So CNG with lower C/H ratio will produce less carbon emission in comparison to the conventional fuel. Due to wider flammability limit, CNG can be burned at high lean mixture leads to the reduction in NO_x emissions.

1.1 Formation of NO_X

When peak temperatures are high enough for long enough periods of time, the nitrogen and oxygen in the air combine to form new compounds, primarily NO and NO_2. These are normally referred to collectively as "NO_x–Nitrogen Oxide". NO_x Emissions is a highly temperature dependent phenomenon and it takes place When the temperature in the combustion chamber exceeds 2000K [4]. The best way to reduce NO_x is to limit the amount of oxygen in the cylinder which results in lower cylinder temperature. Fig no. 1 shows the temperature dependency of NO_x formation. Formation of NO_x is almost absent at temperatures below 2000K. Hence any technique, that can keep the instantaneous local temperature in the combustion chamber below 2000K, will be able to reduce NO_x formation [5].

1.2 Exhaust Gas Recirculation System

The Exhaust Gas Recirculation (EGR) system is designed to reduce the amount of Oxides of Nitrogen (NO_X) created by the engine during operating periods that usually result in high combustion temperature. NO_X is formed in high concentrations whenever combustion temperature exceeds about 2000K. The EGR system reduces NO_X production by re-circulating small amounts of exhaust gases into the intake manifold where it mixes with the incoming air/fuel charge. By diluting the air/fuel mixture under these conditions, it reduces the O_2 concentration in the combustion chamber [6]. Hence, peak temperature and pressure are reduced, resulting in an overall reduction of NO_X.

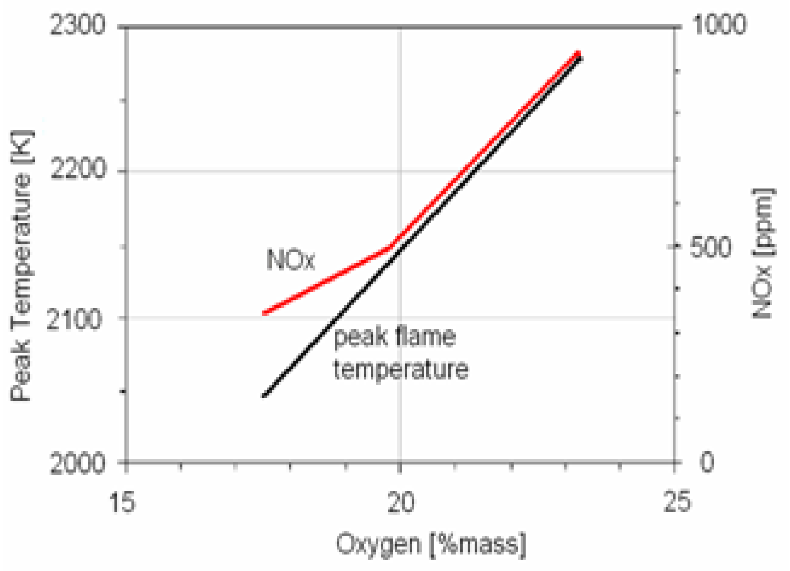

Fig. 1 Temperature dependency of NO_X formation

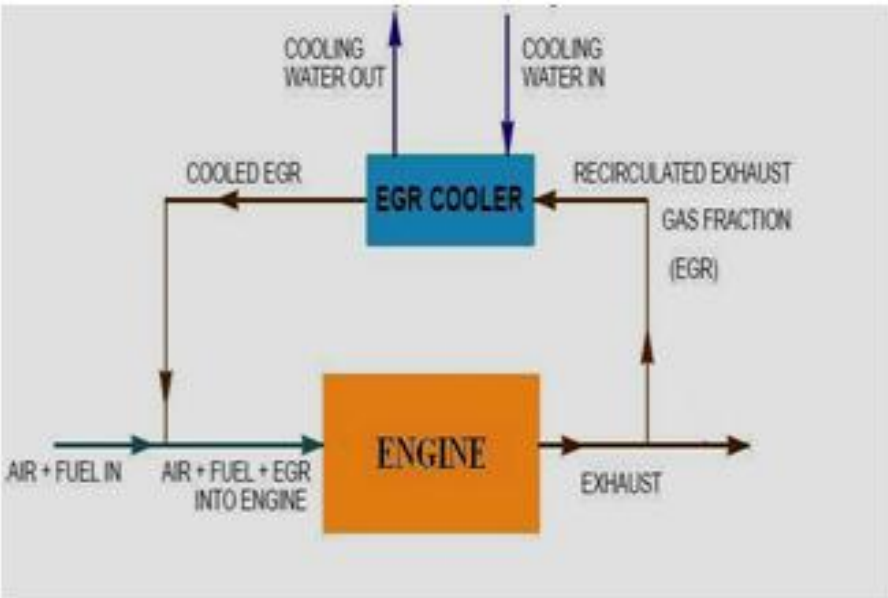

Fig. 2 Schematic of EGR system

Three popular explanations for the effect of EGR on NO_x reduction are increased ignition delay, increased heat capacity and dilution of the intake charge with inert gases. The ignition delay hypothesis asserts that because EGR causes an increase in ignition delay, it has the same effect as retarding the injection timing [7]. The heat capacity hypothesis states that the addition of the inert exhaust gas into the intake increases the heat capacity (specific heat) of the non-reacting matter present during the combustion. The increased heat capacity has the effect of lowering the peak combustion temperature thus decreasing the temperature rise for the same heat release in the combustion chamber [8]. According to the dilution theory, the effect of EGR on NO_x is caused by increasing amounts of inert gases in the mixture, which reduces the adiabatic flame temperature.

1.3 EGR in SI Engine

The exhaust gas, added to the fuel, oxygen, and combustion products, increases the specific heat capacity of the cylinder contents, which lowers the adiabatic flame temperature. In a typical automotive spark-ignited (SI) engine, 5% to 15% of the exhaust gas is routed back to the intake as EGR. The maximum quantity is limited by the need of the mixture to sustain a continuous flame front during the combustion event; excessive EGR in poorly set up applications can cause misfires and partial burns. The impact of EGR on engine efficiency largely depends on the specific engine design, and sometimes leads to a compromise between efficiency and NO_x emissions. With the use of EGR, there is a trade-off between reduction in NO_x and increase in soot, CO and unburned hydrocarbons. It is indicated that for more EGR%, particulate emissions increase significantly and therefore use of a particulate trap is recommended [9].

1.4 EGR Cooler

In EGR systems, the exhaust is needed to be cooled before it's mixed with the gas. Therefore, fuel mixed with exhaust burns cooler and less likely to produce NO_x [10]. The lower temperatures also help fuel economy. The lower temperatures also help to avoid heat transfer energy losses, meaning that more of the car's energy goes into providing power for its wheels.Therefore we need an EGR Cooler (Heat Exchanger) to lower the Exhaust gas temperature. Heat Exchanger is equipment that permits to transfer heat from a hot fluid to a cold one without any direct contact of fluids.

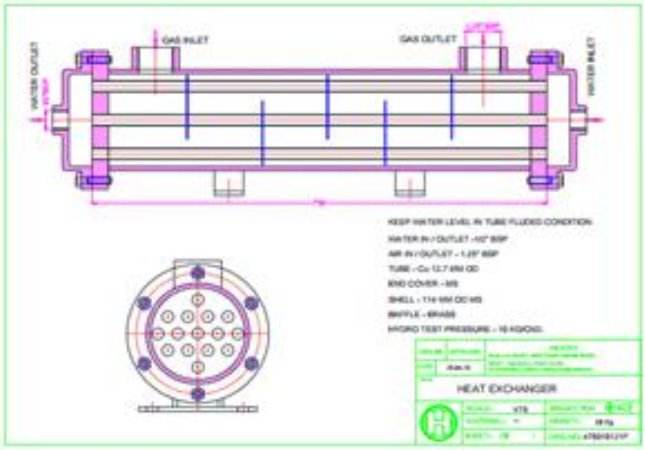

Fig. 3 AUTOCAD drawing of EGR cooler

II. Experimentation

The trials were conducted on computerized three cylinder 4-stroke petrol engine with eddy current dynamometer. Model Maruti 800, Type 3 Cylinder, 4 Stroke, Petrol (MPFI), water cooled, Power 27.6KW at 5000 rpm, Torque 59 NM at 2500rpm, stroke 72 mm, bore 66.5mm, 796 cc, CR 9.2 Engine jacket cooling water flow rate and calorimeter water flow rate was kept constant at 1000 lit/hr and 225lit/hr respectively. The speed of the engine was kept constant at 3000 rpm. Equivalence ratio was also kept constant i.e. 1. Experiments were done at wide open throttle (WOT) & at maximum brake torque (MBT).Known quantity of exhaust gas is re-circulated into the combustion chamber with air. And it is achieved with manually controlled EGR valve. The exhaust gas comes out at very high temperature and pressure. It is pulsating in nature.

An EGR cooler is designed and fabricated to reduce the temperature of exhaust gas. Gate valve is used to control the flow of exhaust gas. Valves are used to control the water supply to the cooler. Digital control panel i.e. IC Engine Analysis Software is provided to acquire data such as torque, fuel, air, water flow of engine and calorimeter. A gas analyzer is used to measure the exhaust pollutants such as O_2, CO, CO_2, HC and NO_X. Gasoline and CNG are supplied to engine. EGR % is calculated by using water manometer.

EGR % = mass of exhaust gas / (mass of exhaust gas + mass of air) * 100
= change in water manometer level / initial water manometer level * 100
The components of EGR cooler and experimental Setup is shown in fig 4

Fig. 4 EGR cooler

Thus with the help of ECU, Experimentation can be done easily and give spontaneous values of speed and load values. The Fig. 4 shows the engine setup with EGR cooler. Exhaust Gas Analyzer is used for finding emission levels of HC, CO and NO_x in ppm. This gives data about Exhaust Gas to be re-circulated so that system performs satisfactorily or not.

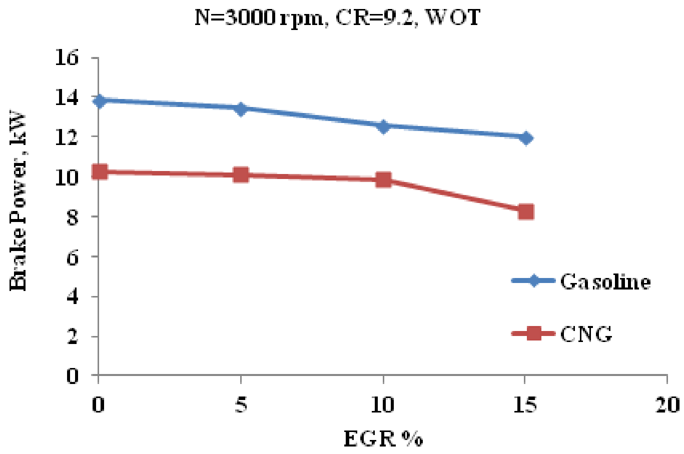

Fig. 5 Brake Power as a function of EGR

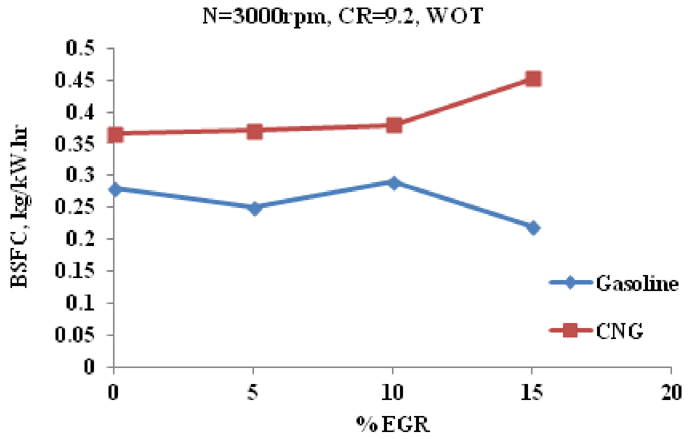

Fig. 6 BSFC as a function of EGR

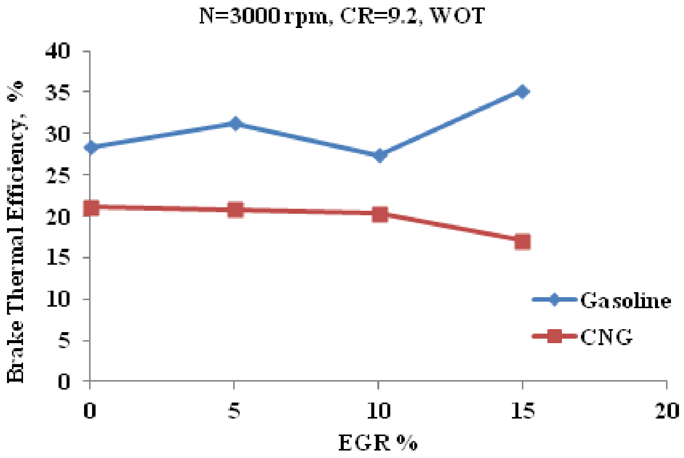

Fig. 7 BTE % as a function of EGR

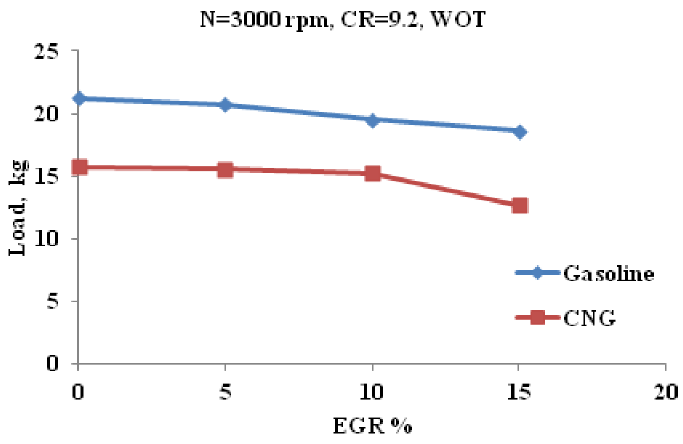

Fig. 8 Load as a function of EGR

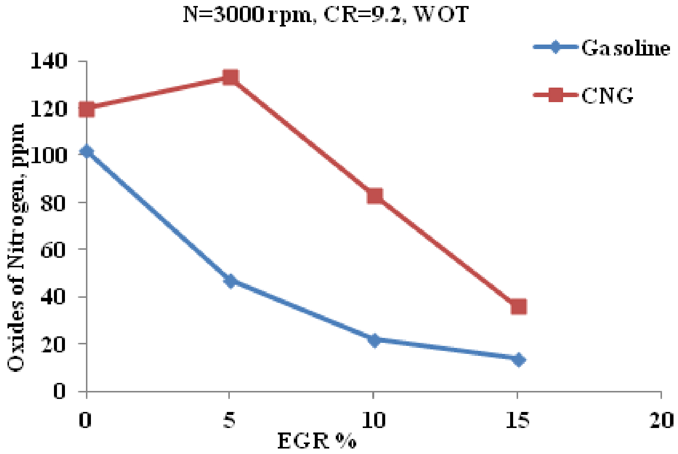

Fig. 9 Oxides of Nitrogen as a function of EGR

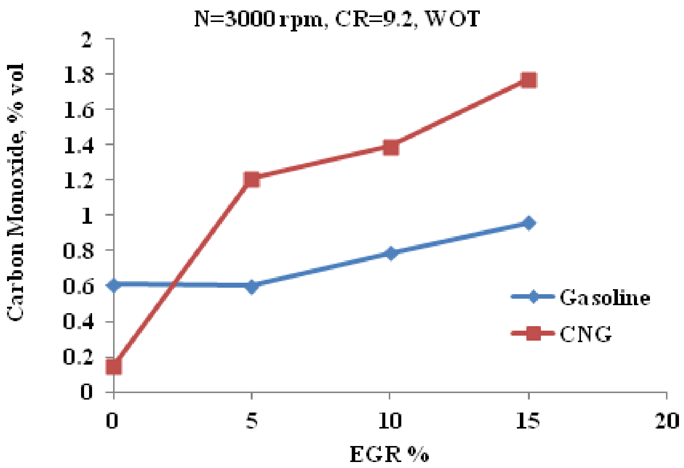

Fig. 10 CO% as a function of EGR

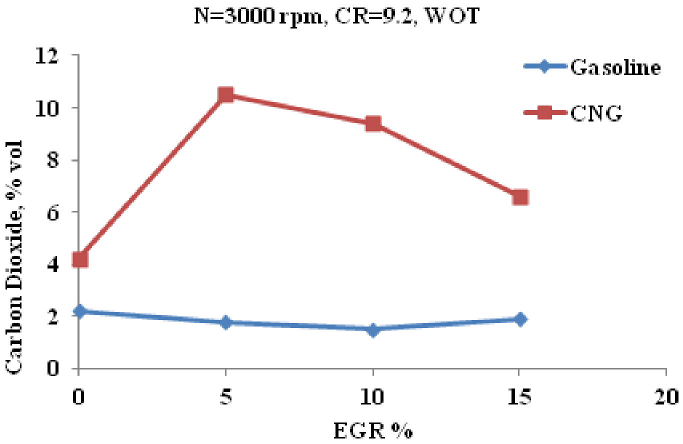

Fig. 11 CO_2 as a function on EGR

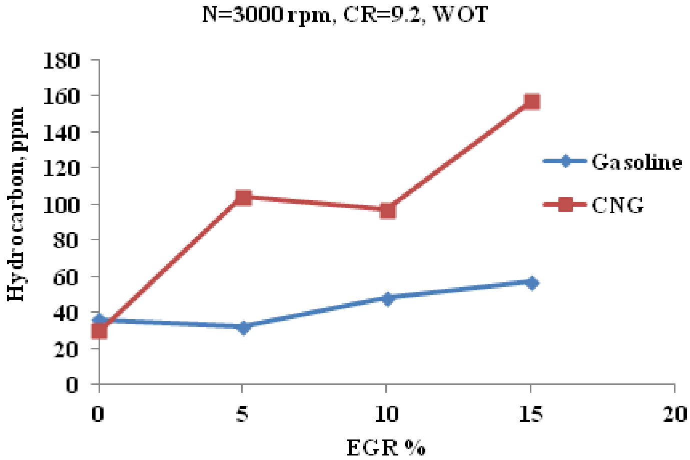

Fig. 12 Hydrocarbon as a function of EGR

The main objective of the present investigation was to evaluate suitability of Exhaust Gas Recirculation system for use in a S.I. engine and to evaluate the performance and emission characteristics of the engine. The experimental study shows the following results:

- Brake Power (BP) for gasoline reduces by 3%, 9% & 13% by implementing 5%, 10% & 15% EGR respectively. BP for CNG reduces by 2%, 4% & 19% by implementing 5%, 10% & 15% EGR respectively. BP was more for gasoline as compared to CNG.
- Load reduces after implementing EGR. Load is more for gasoline as compared to CNG
- Emission of Oxide of Nitrogen (NO_X) was very much reduced by implementation of EGR system from 45 % to 90 %.
- Carbon Mono-oxide (CO) was increased due to incomplete combustion.
- Emission of Carbon Dioxide (CO_2) increases in EGR system
- Emission of Hydro Carbon (HC) increases by implementing EGR system with engine than that of operating engine without EGR system.
- CNG with EGR produces less emission (CO, CO_2, and NOx) than Gasoline with EGR.
- Gasoline with EGR has more load carrying capacity, brake power & brake thermal efficiency than CNG with EGR.
- With increase in EGR % less fuel is required. So, it is fuel efficient.

Hence, we can conclude that CNG with EGR produces less emissions and optimum performance than gasoline with EGR. CNG is highly attractive fuel for vehicles and will become more important due to the increasing demand of cleaner fuels and ever tightening emission norms

Advantages of EGR

- Reduces $NO_{X.}$
- Improved engine life through reduced cylinder temperatures (particularly exhaust valve life).

- Reduced throttling losses. The addition of inert exhaust gas into the intake system means that for a given power output, the throttle plate must be opened further, resulting increased inlet manifold pressure and reduced throttling losses.
- Reduced heat rejection, Lowered peak combustion temperatures not only reduces NO_X formation, it also reduces the loss of thermal energy to combustion chamber surfaces, leaving more available for conversion to mechanical work during the expansion stroke.

Disadvantages of EGR

- Since EGR reduces the available oxygen in the cylinder, the production of particulates (fuel which has only partially combusted) is increased when EGR is applied. This has traditionally been a problem with engines, where the trade-off between NO_x and particulates is a familiar one to calibrators.
- The deliberate reduction of the oxygen available in the cylinder will reduce the peak power available from the engine. For this reason the EGR is usually shut off when full power is demanded, so the EGR approach to controlling NO_X fails in this situation.
- The re-circulated gas is normally introduced into the intake system before the intakes divide in a multi-cylinder engine. Despite this, perfect mixing of the gas is impossible to achieve at all engine speeds / loads and particularly during transient operation. For example poor EGR distribution cylinder-to-cylinder may result in one cylinder receiving too much EGR, causing high particulate emissions, while another cylinder receives too little, resulting in high NO_X emissions from that cylinder.

Future Scope

- CNG is far more affordable than the commonly used fuels like petrol and diesel and can lead to significant cost savings.
- Since the common practice is to modify existing petrol and diesel engines to CNG, optimization of the engine for CNG as fuel is very difficult or not possible. Dedicated CNG engines can further increase the performance of the vehicles.
- NO_X emissions can be drastically reduced by blending small quantities of hydrogen gas with the CNG.
- Using Exhaust Gas Recirculation (EGR) Technique in engines, NO_X emissions are very much controlled. This method is very reliable in terms of fuel consumption.

EGR Systems for petrol engine should excel through the following characteristics:

- Excellent dynamics
- Electrical EGR valves
- High control quality / good metering across the flow rate range
- Good mixing of exhaust gas and fresh air with specifically adapted housing
- Sufficient EGR rates in the desired load range and exhaust gas back pressure range
- Excellent reliability, durability and robustness
- High resistance to contamination
- Small installation volume and low weight
- High temperature resistance
- Low level of leaks

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