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Exhaust Gas Recirculation System

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ABSTRACT

It is today undoubted that humans have to reduce their impacton the environment. Internal combustion engines, being the major power source in the transportation sector as well as inindividual transport, 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 diesel engine provides a high efficiency and hence it canhelp to reduce CO2 emissions, which are believed to be themain cause of global warming. Diesel exhaust also contains toxic gases, mainly nitrogen oxides (NOX) and soot particles. These emissions are therefore limited by the authorities in most countries. A way to reduce the nitrogen oxide emissions of a diesel engine is the use of exhaust gas recirculation, EGR. Here, a part of the exhaust gases is rerouted into the combustion chamber. This leads to a lower peak combustion temperature which in turn reduces the formation of NOX. In modern turbocharged engines it can be problematic to provide the amount of EGR that is needed to reach the emission limits. Other concerns can be the transient response of both the EGR-system and the engine. This work provides a simulative comparison of different EGRsystems,such as long-route EGR, short-route EGR, hybrid EGR, a system with a reed valve and a system with an EGR pump. Both the steady-state performance and transient performance are compared. In steady-state the focus is the fuel efficiency. In transient conditions both the reaction on changed EGR-demands and the torque response are analyzed.

Keyword: *Recirculation System, power source, Gas, energy supply, Pollutants.*

INTRODUCTION

Better fuel economy and higher power with lower maintenance cost has increased the popularity of diesel engine vehicles. Diesel engines are used for bulk movement of goods, powering stationary/mobile equipment, and to generate electricity more economically than any otherdevice in this size range. In most of the global car markets, record diesel car sales have been observed in recent years. The exhorting anticipation of additional improvements in diesel fuel and diesel vehicle sales in future have forced diesel engine manufacturers to upgrade thetechnology in terms of power, fuel economy and emissions. In recent year due to globalization and industrial development, transportation industries are flourishing very fast. Such industries are very much responsible for atmospheric pollution which is detrimental to human health and environment. Internal combustion engines are the main power source for the automobile vehicles which is used by transportation industries. Mostly all the diesel engines have high thermal efficiencies because of their high compression ratio and lean air-fuel operation.

The high compression ratio produces the high temperatures required to achieve auto ignition and the resulting high expansion ratio makes the engine discharge less thermal energy in the exhaust. Due to lean air-fuel mixture, extra oxygen in the cylinders is present to facilitate complete combustion. Increasing diesel consumption increases the pollutant that pollutes the atmospheric air. Thus good efforts are being made to reduce the pollutants emitted from the exhaust system without loss of power and fuel consumption. Recent concern over development in automotive technology is the low environmental impact. In fact, partial recirculation of exhaust gas, which is not a new technique, has recently become essential, in combination with other techniques for attaining lower emission levels. The development of a new generation of exhaust gas recirculation (EGR) valves and improvements in electronic controls allow a better EGR accuracy and shorter response time in transient condition.Pollutants are because of the incomplete burning of the air-fuel mixture in the combustion chamber. The major pollutants emitted from the exhaust due to incomplete combustion are,

1. Carbon monoxide (CO)
2. Hydrocarbons (HC)
3. Oxides of nitrogen (NOx)

If, combustion is complete, the only products being expelled from exhaust would be water vapour which is harmless, and carbon dioxide, which is an inert gas and, as such it is not directly harmful to humans.

1.1 MECHANISM OF FORMATION OF POLLUTANTS

i. Carbon Monoxide (CO)

Carbon monoxide (CO) is a colorless, odorless, and tasteless gas that is slightly lighter than air.It is toxic to humans and animals when encountered in higher concentrations. CO is generallyformed when the mixture is rich in fuel. The amount of CO formation increases as the mixturebecomes more and more rich in fuel. A small amount of CO will come out of the exhaust evenwhen the mixture is slightly lean in fuel because air fuel mixture is not homogenous andequilibrium is not established when the products pass to the exhaust. At the high temperaturedeveloped during the combustion, the products formed are unstable and following reactions takeplace before the equilibrium is established.

$2C+O_2 = 2CO$

As the products cool down to exhaust temperature, major part of CO reacts with oxygen to formCO2. However, a relatively small amount of CO will remain in exhaust.

ii. Hydrocarbons (HC)

Hydrocarbons, derived from unburnt fuel emitted by exhausts, engine crankcase fumes andvapour escaping from the carburettor are also harmful to health. Hydrocarbons appears in exhaustgas due to local rich mixture pockets at much lower temperature than the combustion chamberand due to flame quenching near the metallic walls. A significant amount of this unburnt HCmay burn during expansion and exhaust strokes if oxygen concentration and exhaust temperatureis suitable for complete oxidation.

iii. Mechanism of formation of nitric oxide (NOx)

Oxides of nitrogen is produced in very small quantities can cause pollution. While prolongedexposure of oxides of nitrogen is dangerous to health. Oxides of nitrogen which occurs only inthe engine exhaust are a combination of nitric oxide (NO) and nitrogen dioxide (NO2). Nitrogenand oxygen react at relatively high temperature. NOx is formed inside the combustion chamberin post-flame combustion process in the high temperature region. The high peak combustiontemperature and availability of oxygen are the main reasons for the formation of NOx. In thepresent of oxygen inside the combustion chamber at high combustion temperatures the followingchemical reactions will takes place behind the flame

N2+O2 = 2NO

N2+2H2O = 2NO+H2

Calculation of chemical equilibrium shows that a significant amount of NO will be formed at theend of combustion. The majority of NO formed will however decompose at the low temperaturesof exhaust. But, due to very low reaction rate at the exhaust temperature, a part of NO formed remains in exhaust. The NO formation will be less in rich mixtures than in lean mixtures. The concentration of oxides of nitrogen in the exhaust is closely related peak combustion temperature inside the combustion chamber.

1.2.NOx EMISSION CONTROL

NOx emission is closely related to temperature and oxygen content in the combustion chamber.Any process to reduce cylinder peak temperature and concentration of oxygen will reduce the oxides of nitrogen. This suggests a number of methods for reducing the level of nitrogen oxides. Among these the dilution of fuel-air mixture entering the engine cylinder with an inert or non-combustible substance is one which absorbs a portion energy released during the combustion, thereby affecting an overall reduction in the combustion temperature and consequently in the NOx emission level. The following are the three methods for reducing peak cycle temperature and thereby reducing NOx emission.

I. Water injection.

II. Catalyst

III. Exhaust gas recirculation (EGR)

I. Water injection

Nitrogen oxidesNOx reduction is a function of water injection rate. NOx emission reduces withincrease in water injection rate per kg of fuel. The specific fuel consumption decreases a few percent at medium water injection rate. The water injection system is used as a device for controlling the NOx emission from the engine exhaust.

II. Catalyst

A copper catalyst has been used to reduce the NOx emission from engine in the presence of CO.Catalytic converter package is use to control the emission levels of various pollutants by changing the chemical characteristics of the exhaust gases. Catalyst materials such as platinumand palladium are applied to a ceramic support which has been treated with an aluminium oxide wash coat. This results in as extremely porous structure providing a large surface area to stimulate the combination of oxygen with HC and CO. This oxidation process converts most of these compounds to water vapour and carbon dioxide

III. Exhaust Gas Recirculation.

Exhaust Gas Recirculation is an effective method of NOx control. The exhaust gases mainlyconsist of carbon dioxide, nitrogen etc. and the mixture has higher specific heat compared to atmospheric air. Re-circulated exhaust gas displaces fresh air entering the combustion chamber with carbon dioxide and water vapor present in engine exhaust. As a consequence of this air displacement, lower amount of oxygen in the intake mixture is available for combustion.

Reduced oxygen available for combustion lowers the effective air–fuel ratio. This effective reduction in air–fuel ratio affects exhaust emissions substantially. In addition to this, mixing of exhaust gases with intake air increases specific heat of intake mixture, which results in the reduction of flame temperature. Thus combination of lower oxygen quantity in the intake air and reduced flame temperature reduces rate of NOx formation reactions .The EGR (%) is defined as the mass percent of the recirculated exhaust (MEGR) in the total intake mixture (Mt).

EGR (%) = (MEGR ÷ Mt) × 100

From above three methods, EGR is the most efficient and widely used system to control the formation of oxides of nitrogen inside the combustion chamber of I.C. engine. The exhaust gas for recirculation is taken through an orifice and passed through control valves for regulation of the quantity of recirculation.

2EXHAUST-GAS RECIRCULATION SYSTEM

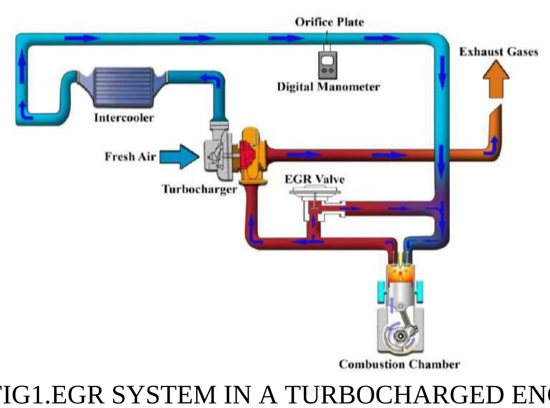

FIG1.EGR SYSTEM IN A TURBOCHARGED ENGINE

When EGR system is applied, the engine intake consists of fresh air and recycled exhaust gas.Exhaust gases were tapped from exhaust pipe and connected to inlet airflow passage. An EGR control valve was provided in this pipe for EGR control. The exhaust gases were regulated by this valve and directly send to the inlet manifold, upstream of compressor or downstream of compressor. Sufficient distance for through mixing of fresh air and exhaust gases were ensured. The above shown system is also called as hot EGR because it not fitted with an EGR cooler which is used to cool the intake mixture. A typical EGR valve is shown below.

FIG 2.EGR VALVE [AMA OIL TECHNICAL SERVICE BULLETIN]

2.1TYPES OF EGR SYSTEMS

1.LOW PRESSURE EGR SYSTEMS

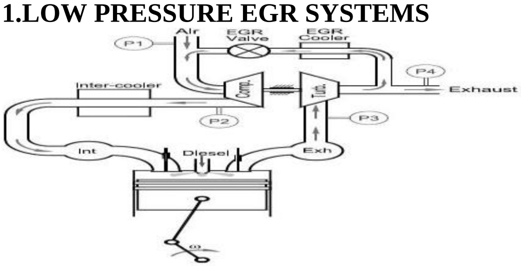

FIG 3.LOW PRESSURE EGR SYSTEM

If portion of turbine outlet exhaust gas is delivered to compressor inlet through the flow control valve then it called low pressure EGR loop. In low pressure EGR system, a flow passage is a devised between the exhaust of super charger turbine and the intake manifolds connected to the super charging compressor. The flow of EGR regulated is with a throttling valve showing in Figure above. The pressure differences generally are sufficient to drive the EGR flow of adesired amount except during idling. If the exhaust gas is recycled to the intake directly, the operation is called hot EGR. If the exhaust gas is recycled through EGR cooler, the operation is called cooled EGR.

For turbocharged I.C. engine modification is done in EGR system because a positive differential pressure between the turbine outlet and compressor inlet is generally available (p4-p1)>0. Furthermore, tailpipe pressure p1 can be elevated by partial throttling that ensures sufficient driving pressure for the EGR flow. The low pressure EGR loop is not applicable as the conventional compressor and inter–coolers are not designed to ensure the temperature of exhaust gas.

This type of loop can be used by directing exhaust from the turbine outlet to the inter-cooler outlet directly bypassing the compressor.

2.HIGH PRESSURE EGR SYSTEMS

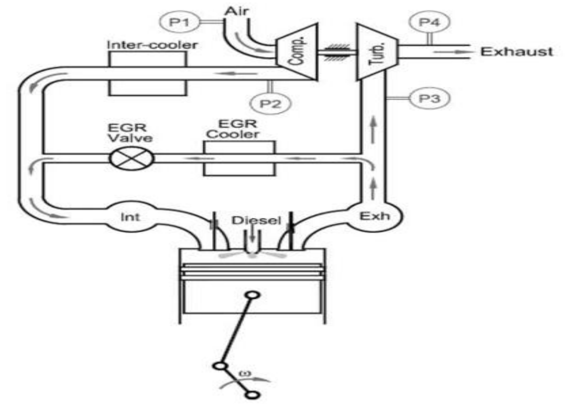

FIG 4. HIGH PRESSURE EGR SYSTEM

Another method of EGR is high pressure EGR loop. In high pressure EGR system, a flowpassage is devised between the exhaust of engine (up-stream of the turbine) and the intake manifolds of engine (downstream of the super charging compressor).

In this system the exhaust gas is recirculate from upstream of the turbine to downstream of the compressor or the downstream of the inter-cooler as shown in Figure. The compressor and intercooler are therefore not exposed to the exhaust gas. Such high pressure loop EGR system is only applicable when the turbine upstream pressure is sufficiently higher than the boost pressure (compressor downstream pressure) i.e. if (P3-P2)>0.

2.2 SCHEMATIC DIAGRAM OF ENGINE SETUP USING EGR IN A CONSTANT SPEED DIESEL ENGINE

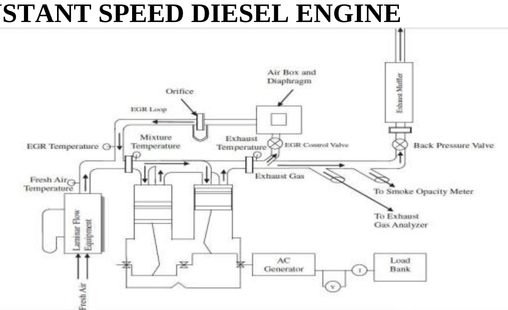

FIG 5. ENGINE SETUP USING EGR IN A CONSTANT SPEED DIESEL ENGINE

This figure shows a two-cylinder constant speed diesel engine generator set. This was chosen tostudy the effect of EGR. The engine is coupled with an AC generator and the current generated is used by a resistive load bank, thus in-turn loading the engine. An air box was provided in EGR loop to dampen the fluctuations of the pulsating exhaust. An orifice was installed in the EGR loop to measure the flow rate of re-circulated exhaust gas. To measure the intake air flow rate, a laminar flow equipment (LFE) was installed. Suitable instrumentation for measurement of temperatures at several locations was done. Fuel consumption measurement was done using a gravimetric fuel consumption meter. Exhaust gas emission measurements were done by raw exhaust gas emission analyzer. NOx emissions were analyzed by a Chemilumine scence Analyzer.

3. EFFECT OF EGR ON NOx EMISSION IN ENGINES

3.1CONSTANT SPEED DIESEL ENGINE

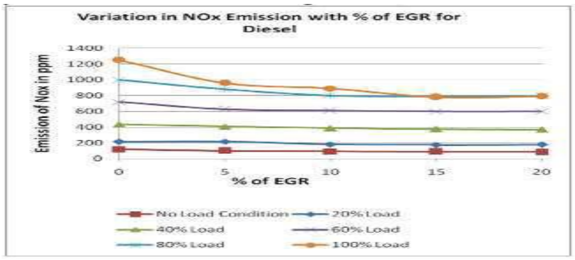

FIG 6.EFFECT OF EGR NOx EMISSINON IN CONSTANT SPEED DIESEL ENGINE

Exhaust gas recirculation (EGR) is a pre-treatment technique. This is the widely used process to reduce and control the oxides of nitrogen (NOx) emissions from diesel engines. EGR control the NOx because it lowers oxygen concentration and flame temperature of the working fluid in the combustion chamber. The exhaust gas displaces fresh air-entering the combustion chamber and this air displacement lowers the amount of oxygen available for combustion in the intake mixture. Reduced oxygen available for combustion lowers the effective air-fuel ratio.

Exhaust gases mixed with intake air increases specific heat of intake mixture, which results in the reduction of flame temperature. Thus combination of lower oxygen quantity in the intake air and reduced flame temperature reduces rate of NOx formation. Engine using EGR emit lower quantity of exhaust gases compared to non-EGR engines because part of the exhaust gas is recirculated. Diesel engines operating at low loads are generally tolerate a higher EGR ratio because re-circulating exhaust gases contain high concentration of oxygen and low concentration of carbon dioxide. But at higher loads, the oxygen in exhaust gas becomes scare and inert constituents start dominating along with increased exhaust temp. Thus as load increases, diesel engines tend to generate more smoke because of reduced availability of oxygen. At very high EGR rate (around 44%) NOx emission continuously drops but this high EGR rate significantly affects the fuel economy. The degree of reduction in NOx at higher loads is higher with same % EGR compared to part load. At the part load, O2 is available in sufficient quantity but at high loads O2 reduces drastically, therefore NOx is reduced more at higher loads compared to partloads.

The major influence on NOx emission is due to change in temperature rather than O2 availability. About 15% EGR rate is found to be effective to reduce NOx emission substantially without deteriorating performance and emission. At higher loads, increased rate of EGR reduces NOx to a greater extent but deteriorates the performance and emissions. Therefore higher EGR rates can be applied at lower loads.

3.2EFFECT OF EGR ON NOx EMISSIONS OF OTHER ENGINES

3.2.1 ENGINE FUELLED WITH JETROPHA BIO-DIESEL

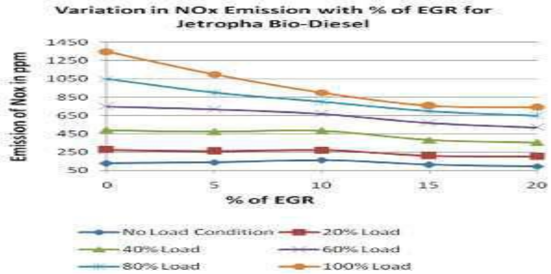

FIG 7.EFFECT OF EGR ON NOx EMISSION INENGINE USING JETROPHA BIODIESEL

NO emission from engine fueled with jetropha biodiesel was found to be comparatively higher than the engine fueled with diesel at full load and at part load with 0% EGR operation. This is due to higher viscosity of bio-diesel resulting in a dynamic injection advance apart from state injection advance provided for optimum efficiency and excess oxygen present in the jetrophabio-diesel. With 5% EGR, the NO level comes down for jathropha bio-diesel and for diesel fuelled engine but still NO level is higher for jathropha bio-diesel than for diesel at full load operation. For jathropha bio-diesel NO levels were found to be increasing for load range 0-40% for 5% and10% EGR operation. These values were found to be higher compared to both diesel and jetropha biodiesel without EGR because of the increased charge temperature due to hot EGR and dynamic injection advance. NO emission from jetropha bio-diesel at all loads for 15% EGR rate was lower compared to diesel without EGR condition. 20 to 25 % EGR were able to reduce NO level by a large amount but it will increases smoke, CO and HC emission. 15% hot EGR reduces NO emission without much adverse effects on the performance, smoke and other emissions. 15% EGR on jetropha bio-diesel was found to be effective in reducing NO emission to values lower than that of diesel without EGR at all loads. At full load, 15% EGR on jetropha bio-diesel was found to be lower than that of corresponding diesel NO emission with 15% EGR.

3.2.2 HEAVY DUTY DIESEL ENGINE

In heavy duty DI diesel engines NOx emission decreases almost linearly with EGR rate. NO emissions at full load remain almost constant when altering EGR temp. A small NO emission increases only at high EGR rates. Formation of NOx is temperature and O2 sensitive. So that the increase of EGR temperature is compensate by the reduction of air fuel ratio. For the same EGR rate has no significant effect on NO for all engines speeds, but small NO emission increases only at high EGR rates with speed on the other hand. The effect of EGR rate is slightly higher at low engine speed. Emission of NO increases with increase of temperature of EGR (hot EGR) compared to the cooled EGR. The increase of EGR temperature from 90°C to 240 °C results to an increase of the mean gas temperature and the individual zone temperature during the main combustion period and that create adverse effect on NO emission. Because of that, in heavy duty DI diesel engine, EGR cooling is favorable to retain the benefits of law NOx emissions without sacrificing the engine efficiency.

3.2.2 LPG FUELLED DIESEL ENGINE

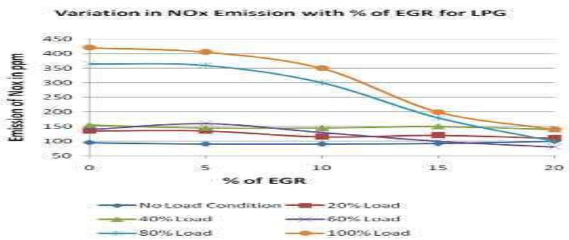

FIG 8.EFFECT OF EGR ON NOx EMISSION IN ENGINE USING LPG

Diesel engine was operated on 100% liquefied petroleum gas (LPG). The LPG has a low cetane number (<3). Therefore diethyl ether was added to the LPG for ignition purpose. It will improve the cetane number (>125) and has a low auto ignition temperature (160 °C). Exhaust gas recirculation (EGR) is one of the most effective techniques for reducing NOx emission from I.C.engines.

EGR raises the total heat capacity of working gases in engine cylinder and lowers the peak temperature due to high heat capacity of EGR. The concentration of NOx in the case ofLPG operation without EGR is about 60% less than NOx concentration in the case of dieselengine operation at any load. For LPG engine it is observed that for all EGR percentages, the NO emission is found slightly higher compared to LPG operation without EGR from no load to 40% load. This is because the exhaust gas mixes with intake air and raises the inlet air temperature slightly.

This EGR will enhance the combustion rate and leading to increased cylinder peak temperature and hence higher NO emissions in the engine exhaust. But at higher power outputs, significant reduction in NOx concentration particularly with 10% to 20% of EGR from 80% to 100% load. This may be due to the fact that at higher loads as well as with higher EGR percentages, the concentration of both CO2 and H2O present in the intake is more. These gases absorb energy released by combustion, which reduces the peak combustion temperature in the combustion chamber resulting in the reduction of NO emission.

Also LPG with EGR operation exhibits lower exhaust gas temperature particularly with high EGR percentages at higher loads.

3..2.3. **DIESEL ENGINE WITH HYDROGEN AS DUAL FUEL**

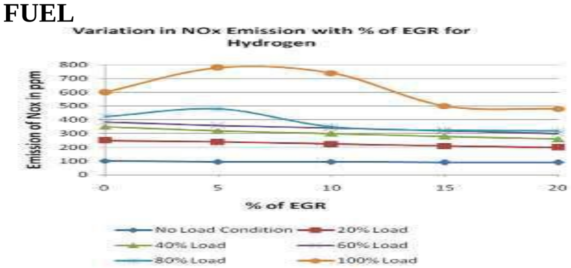

FIG 9.EFFECT OF EGR ON NOX EMISSION IN ENGINE USING HYDROGEN AS DUAL FUEL

Hydrogen is one of the best alternatives for conventional fuels. Hydrogen enriched air is used asintake charges in a diesel engine adopting exhaust gas recirculation (EGR). The main pollutant exhausted by hydrogen fueled engine is NOx. NOx emission from hydrogen duel fuel engine without EGR is higher than the diesel engine. But with EGR, the NOx formation decreases with increase in the EGR. This is mainly due to the replacement of air-fuel mixture by inert gas, which reduces the peak combustion temperature.

4. EFFECTS OF EGR ON ENGINE PARTS

The physical conditions of various vital engine parts which are directly exposed to combustion in-cylinder liner are shown in Figures.

Fig.10 Carbon deposits on cylinder head 1) with EGR, 2) without EGR

Fig.11 Carbon deposits on injector tip 1) with EGR, 2) without EGR

Fig.12 Carbon deposits on piston crown 1) with EGR, 2) without EGR

It can be clearly seen that carbon deposits on the various parts of the engine operated with EGR system is significantly more than that of engine operated without EGR. The higher carbon deposits in the EGR system seem to be because of higher soot formation.

5. WEAR OF PISTON RINGS

The piston rings are one of the most important components in the engine, which are essential for operation of the engine. Piston rings are subjected to high thrust imposed by combustion gases. Rings are used to reduce the friction between cylinder liner surface and the piston.

They are made of very high strength material so that they can resist high temperature and high thrust of combustion process and at the same time have very low wear. In the engine using EGR, top compression ring faces lowest weight loss compared to other rings. The weight loss of top compression ring is about 0.30% of the initial weight of ring. The oil ring faces highest amount of weight loss in the engine using EGR. The amount of wear was approximately 0.90% of initial weight.

It has been observed that the extent of wear of top ring in the engine using EGR is lower than normal operating engine. The possible reason of this may be the lower temperature of the combustion chamber of the engine using EGR. However, the wear rate of second and third compression ring and oil ring is comparatively higher for engine using EGR. The possible reason for this may be presence of higher amount of soot and wear debris in the lubricating oil of the engine using EGR.

6.CONCLUSION

Thus, as seen that using Exhaust Gas Recirculation Technique in engines, the emissions are very much controlled due to lesser amounts of NOx entering the atmosphere. Exhaust gases lower the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. Thus the emission levels to be maintained are attained by the engines. It can be observed that 15% EGR rate is found to be effective to reduce NOx emission substantially without deteriorating engine performance.

As seen, Exhaust Gas Recirculation is a very simple method. It has proven to be very useful and it is being modified further to attain better standards. This method is very reliable in terms of fuel consumption and highly reliable. Thus EGR is the most effective method for reducing the nitrous oxide emissions from the engine exhaust. Many of the four wheeler manufacturers like Ford Company, Benz Motors etc used this technique to improve the engine performance and reduce the amount of pollutants in the exhaust of the engine.

REFERENCES

1. Deepak Agarwal ,Shrawan Kumar Singh , Avinash Kumar Agarwal: Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine(2011)3-7
2. Harilal S. Sorathia ,Dr.Pravin P. Rahhod and Arvind S. Sorathiya: Effect of EGR on NOxemission in CI engines: A review study(2012)1-5
3. M. Gomaa, A.J. Alimin, K.A. Kamarudin: The effect of EGR rates on NOX and smoke emissions of an IDI diesel engine fuelled with Jatropha biodiesel blends(2011)3-4
4. Ming Zheng , Graham T. Reader , J. Gary Hawley : Diesel engine exhaust gasrecirculation—a review on advanced and novel concepts(2004)3-5

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