Title: Review on Nox Reduction of CI Engine Exhaust by Using EGR and SCR and its Impact on Efficiency of Engine

Mr. Rajat S. Jadhav[1], Mr. Deepak B. Jadhav[2], Mr.M.E.Nimgade[3]

[1]*T.E, Mechanical Engineering, Smt. Kashibai Navale College of engineering Pune,* ***rajatjadhav8928732210@gmail.com***
[2]*T.E, Mechanical Engineering, Smt. Kashibai Navale College of engineering Pune,* ***deepak.jadhav426@gmail.com***
[3]*Assistance Professor, Mechanical Engineering,Smt. Kashibai Navale College of engineering Pune,,****menimgade@sinhgad.edu***

ABSTRACT

It is today undoubted that humans have to reduce their impact on the environment. Internal combustion engines, being the major power source in the transportation sector as well as in individual 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 can help to reduce CO2 emissions, which are believed to be the main 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.

---

1. INTRODUCTION

Growing concern about pollution led to the establishment of EURO-VI pollution norms in Europe. And on the same grounds Indian Government is establishing Bharat Stage –VI norms directly after Bharat Stage-IV skipping the fifth one. These new established laws demand to reduce the emissions by about 90%. It simply means that reduce the emissions of your vehicle by 90% and only then you can sell your vehicle in the Indian
market. To meet these new emission levels we have to invent the news technologies and use new strategies.
Amongst the many strategies following two are extensively used-
1. EGR- Exhaust Gas Recirculation
2. SCR- Selective Catalytic Reduction
These technologies have some Banes and Boons. One of the major Bane of EGR is reduction inefficiency. And that of SCR is increase in customer burden. Lets discuss these topic in detail one by one.

Euro standard	Introduction date		Emission Limits		
	New approvals	New registration	Petrol NO_x	Diesel NO_x	Diesel PM
EURO I	1 July 1992	31 Dec 1992	0.97g/km	0.97g/km	0.14g/km
EURO II	1 Jan 1996	1 Jan 1997	0.5g/km	0.9g/km	0.1g/km
EURO III	1 Jan 2000	1 Jan 2001	0.15g/km	0.5g/km	0.05g/km
EURO IV	1 Jan 2005	1 Jan 2006	0.08g/km	0.25g/km	0.025g/km
EURO V	1 Sept 2009	1 Jan 2011	0.06g/km	0.18g/km	0.005g/km
EURO VI	1 Sept 2014	1 Sept 2015	0.06g/km	0.08g/km	0.0045g/km

Table1.Emission Norms

2. EXHAUST GAS RECIRCULATION (EGR)

A widely adopted route to reduce NO_x emissions is Exhaust Gas Recirculation (EGR).This involves recirculating a controllable proportion of the engine's exhaust back into the intake air. A valve is usually used to control the flow of gas, and the valve may be closed completely if required. The substitution of burnt gas (which takes no further part in combustion) for oxygen rich air reduces the proportion of the cylinder contents available for combustion.This causes a correspondingly lower heat release and peak cylinder temperature, and reduces the formation of NO_x. The presence of an inert gas in the cylinder further limits the peak temperature (more than throttling alone in a spark ignition engine). The gas to be recirculated may also be passed through an EGR cooler, which is usually of the air/water type. This reduces the temperature of the gas, which reduces the cylinder charge temperature when EGR is employed. This has two benefits- the reduction of charge temperature results in lower peak temperature, and the greater density of cooled EGR gas allows a higher proportion of EGR to be used. On a diesel engine the recirculated fraction may be as high as 50% under some operating conditions.

Advantages

- Reduced NOx
- Potential reduction of throttling losses on spark ignition engines at part load
- Improved engine life through reduced cylinder temperatures (particularly exhaust valve life)

Disadvantages

- 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 diesel 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 EGR valve can not respond instantly to changes in demand, and the exhaust gas takes time to flow around the EGR circuit. This makes the calibration of transient EGR behaviour particularly complex- traditionally the EGR valve has been closed during transients and then re-opened once steady state is achieved. However, the spike in NOx / particulate associated with poor EGR control makes transient EGR behaviour of interest.
- The recirculated 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.
- Although the term EGR usually refers to deliberate, *external* EGR, there is also a level of *internal* EGR. This occurs because the residual combustion gas remaining in the cylinder at the end of the exhaust stroke is mixed with the incoming charge. There is therefore a proportion of *internal* EGR which must be taken into account when planning EGR strategies. The scavenging efficiency will vary with engine load, and in an engine fitted with variable valve timing a further parameter must be considered.

Application of Combustion Analyzers to EGR Development

- Combustion's CLD500 NO_x analyzer offers two channels of simultaneous NO_x measurement, with a $T_{10-90\%}$ of 10ms or less. This allows NO_x concentrations in the exhaust to be measured for each firing cycle, allowing cyclic variability to be observed.
- Combustion's NDIR500 CO&CO_2 analyzer offers two channels of simultaneous CO & CO_2 measurement, with a $T_{10-90\%}$ of 8ms. This allows a variety of applications:
- Sampling with the NDIR500 in the intake allows measurement of CO_2 concentration in the intake charge. Measurement of exhaust CO_2 with the other channel of the NDIR allows calculation of the external EGR rate, on a cycle by cycle basis.

ISSN: 2321-8169
1263 – 1268

- Depending on the location of the intake probe, either the overall EGR rate or the EGR rate specific to one cylinder may be measured. This allows verification and improvement of EGR modeling and EGR distribution, including transients.
- Sampling with the NDIR probes at different points through the EGR loop allows characterization of EGR system delays and behaviour.
- Comparison of the CO_2 concentration in the pre-combustion gas with the exhaust gas from the previous cycle allows total EGR (internal + external) to be calculated. This technique can therefore reveal cyclical variation, as well as cylinder to cylinder variation. Such a capability may also be useful when verifying the effects of variable valve timing.

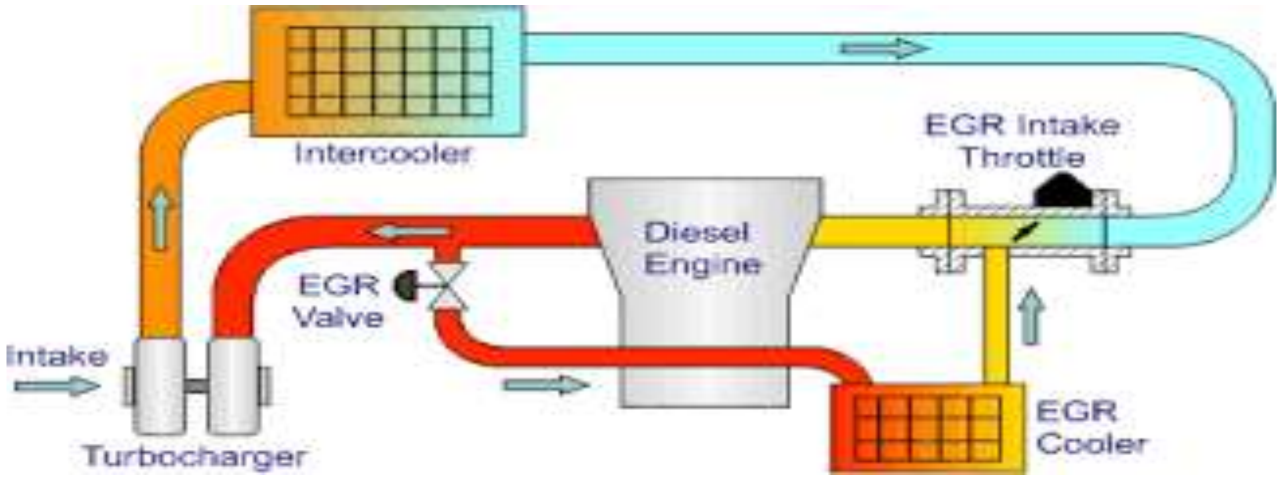

Fig1.EGR system

3. SELECTIVE CATALYTIC REDUCTION

Selective Catalytic Reduction (SCR) is an advanced active emissions control technology system that injects a liquid-reductant agent through a special catalyst into the exhaust stream of a diesel engine. The reductant source is usually automotive-grade urea, otherwise known as Diesel Exhaust Fluid (DEF). The DEF sets off a chemical reaction that converts nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide (CO2), natural components of the air we breathe, which is then expelled through the vehicle tailpipe.

SCR technology is designed to permit nitrogen oxide (NOx) reduction reactions to take place in an oxidizing atmosphere. It is called "selective" because it reduces levels of NOx using ammonia as a reductant within a catalyst system. The chemical reaction is known as "reduction" where the DEF is the reducing agent that reacts with NOx to convert the pollutants into nitrogen, water and tiny amounts of CO2. The DEF can be rapidly broken down to produce the oxidizing ammonia in the exhaust stream. SCR technology alone can achieve NOx reductions up to 90 percent

Why is SCR important?

SCR technology is one of the most cost-effective and fuel-efficient technologies available to help reduce diesel engine emissions. All heavy-duty diesel truck engines produced after January 1, 2010 must meet the latest EPA emissions standards, among the most stringent in the world, reducing particulate matter (PM) and nitrogen oxides (NOx) to near zero levels. SCR can reduce NOx emissions up to 90 percent while simultaneously reducing HC and CO emissions by 50-90 percent, and PM emissions by 30-50 percent. SCR systems can also be combined with a diesel particulate filter to achieve even greater emission reductions for PM. In the commercial trucking industry, some SCR-equipped truck operators are reporting fuel economy gains of 3-5 percent1. Additionally, off-road equipment, including construction and agricultural equipment, must meet EPA's Tier 4 emissions standards requiring similar reductions in NOx, PM and other pollutants.

Where is SCR used?

SCR has been used for decades to reduce stationary source emissions. In addition, marine vessels worldwide have been equipped with SCR technology, including cargo vessels, ferries and tugboats. With its superior return in both economic and environmental benefits, SCR is also being recognized as the emissions control technology particularly helpful in meeting the U.S. EPA 2010 diesel engine emission standards for heavy-duty vehicles and the Tier 4 emissions standard for engines found in off-road equipment. SCR systems are also found in the growing number of diesel passenger vehicles.

What are the special considerations of using SCR?

One unique aspect of a vehicle or machine with an SCR system is the need for replenishing Diesel Exhaust Fluid (DEF) on a periodic basis. DEF is carried in an onboard tank which must be periodically replenished by the operator based on vehicle operation. For light-duty vehicles, DEF refill intervals typically occur around the time of a recommended oil change, while DEF replenishment for heavy-duty vehicles and off-road machines and equipment will vary depending on the operating conditions, hours used, miles traveled, load factors and other considerations.

DEF is an integral part of the emissions control system and must be present in the tank at all times to assure continued operation of the vehicle or equipment. Low DEF supply triggers a series of escalating visual and audible indicators to the driver or operator. Once the tank reaches a certain level near empty, the starting system may be locked out the next time the vehicle is used, preventing the vehicle from being started without adequate DEF. A nationwide DEF distribution infrastructure has rapidly expanded to meet the needs of a growing SCR technology marketplace.

On-board tanks to store DEF are typically located in the spare tire area of passenger vehicles, while tractor trailers typically have a DEF tank alongside the diesel fuel saddle tank. Proper storage of DEF is required to prevent the liquid from freezing at temperatures below 12 degrees Fahrenheit, and most vehicle DEF dispensing systems have warming devices.

What is DEF?

Diesel Exhaust Fluid (DEF) is a non-toxic fluid composed of purified water and automotive grade aqueous urea. DEF is available with a variety of storage and dispensing methods. Storage options consist of various size containers such as bulk, totes and bottles or jugs. The American Petroleum Institute rigorously tests DEF to ensure that it meets industry-wide quality standards.

DEF is available for purchasing at various locations like truck stops, truck dealerships and engine distributors which can be located using one of the below links. DEF tanks range in size from 6 to 23 gallons depending on the truck's application. The DEF tank fill opening is designed to accommodate a DEF fill nozzle to ensure only DEF is put into the tank. A diesel fuel nozzle will not fit into the DEF tank opening.

Most truck manufacturers calculated operating costs of new SCR-equipped vehicles based on a DEF price of $3 per gallon, however, the price of DEF is expected to respond to market conditions of supply and demand and is expected to decrease due to the growing network of DEF supply.

Benefits of SCR

- No power draw to cool the exhaust gases
- No fuel used for active regeneration or to boost SCR performance
- No additional complexity for the manufacturer of the body
- No engine noise during forced regeneration when at a standstill

ISSN: 2321-8169
1263 – 1268

- Lower operating temperatures inside the DPF and no risk of thermal runaway
- Longer oil change intervals (up to 90,000 miles/150,000 km)
- Longest DPF service interval (up to 360,000 miles/600,000 km).
- A much simpler engine means a lower risk of breakdowns.

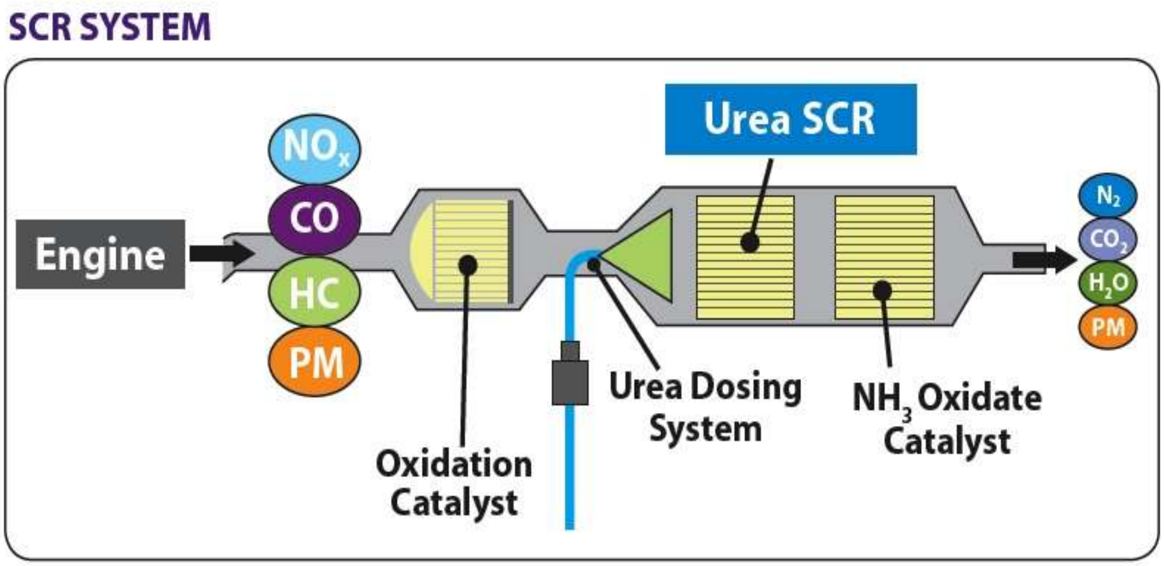

Fig2.SCR system

4. EGR VS SCR

A recent request for help with understanding different emissions technologies to reach the Tier 4 Interim and Final off-highway emissions rules reopened the cooled EGR vs. SCR debate for me. Cooled exhaust gas recirculation, or EGR, is going to be the route most off-highway engine manufacturers are going to take when the rule hits a big chunk of the off-highway market in January 2011.It's interesting, but not surprising, because several have already developed the systems to reach the earlier Tier 3 rules. And Tier 4 Interim is nowhere near as demanding as EPA 2010 on-highway regulations. They're more like the Tier 4 Final, which is due in 2015, by which time most off-highway engines will run similar combinations of EGR and selective catalytic reduction (SCR) as the on-highway counterparts and any issues with either technology or their combination will have been ironed out.But for the looming Tier 4 Interim, one equipment manufacturer, Case, is going down both routes simultaneously, using EGR and SCR individually according to application, duty cycle and so on. That way, Case customers will get either the operator simplicity of EGR or the economy benefits of SCR according to how the construction or agricultural equipment is used. However, customers don't get to chose: Case will make the evaluation and select the technology it thinks will work best.In the technology transfer from on-highway to off-highway emissions, it would be easy to think of Volvo Construction and the equipment manufacturers using Cummins power as the big winners because those companies have already taken engines to close-to-Tier 4 for their highway products. But Case has that advantage, too, as it is part of the mighty Fiat empire and has access to Fiat Powertrain Technologies (a company that commercialized the common-rail diesel engine), and has lots of on-highway experience through the commercial vehicle Iveco brand that is big in southern Europe and elsewhere around the world.So far, there appears to be little being said about reaching Tier 4 Final. Interestingly, John Deere Power is looking at a different approach altogether, perhaps even using an electric drive and a diesel engine running at a constant speed generating the electrical power. That's an interesting approach, allowing for a single speed optimization of the engine and none of the transients to deal with that give the on-highway guys such heartburn.That brings us to Navistar's latest announcement that it will certify the MaxxForce at 0.2 g NOx (currently it is at the 0.5 g level, with emissions credits closing the gap). But the plan is to not sell that engine immediately, but soldier on with the current 0.5 g calibrations.The thought here is that, as Navistar has claimed all along, 0.2 g is doable will all-EGR, but it may bring some fuel economy compromises that the market cannot live with. By delaying the commercial launch of the cleaner engine, Navistar engineers have more time to work out the technological solutions to deliver low engine-out NOx and fuel economy at the same time.Speculation has it that to get down to 0.2 g, there will have to be some sort of add-on technology, similar to the concept proposed by Deere. But that may be a little too radical for truckers at the moment. Far more likely will be an SCR solution that is not urea in solution, if you'll pardon the pun. No messing with a new fluid on the truck, but using ammonia nevertheless.This could be through on-board generation from the diesel fuel, a technology that exists but currently is very expensve. Or it could be from a solid storage medium that has a cartridge that is renewed at oil-change intervals. Navistar has the technology in the Danish company Amminex, which it invested in at the end of last year. This contains the ammonia in a solid salt matrix and gives it up when the cartridge is heated.

REFERENCES

[1] Exhaust Emissions and Driveability — Chrysler Corporation, 1973
[2] Dennis A., Garner C., Taylor D. (1999). *The Effect of EGR on Diesel Engine Wear*, SAE 1999-01-0839, In-Cylinder Diesel Particulate and NOx Control 1999
[3] *"What is the EGR valve and what does it do?"*, *Yahoo! Auto Retrieved* 22 March *2011*
[4] Nagel, John (2002). Diesel Engine and Fuel System Repair
[5] In-Cylinder Diesel Particulate and NOx Control,1999.
[6] Nox reductions and N2O emissions 1. Nox reductions and N2O emissions in diesel engine exhaust using Fe-zeolite and vanadium based SCR catalysts---ELSEVIER
[7] Experimental Study of Nox reduction on medium speed heavy duty diesel engine by application of EGR and Miller timings---ELSEVIER.
[8] Energy Efficiency impact of EGR on organizing clean combustion in diesel engines.---ELSEVIER.
[9] http://www.greencarcongress.com
[10] http://www.egr.msu.edu
[11] http://www.natso.com