A modelling and analysis of exhaust gas recirculation system to lower the NOx emission from internal combustion engine: a review on advanced and novel concepts

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Abstract: Internal combustion (IC) engines emit harmful gases such as HC, CO2, and NOx, etc. Search is on for better alternatives to the fossil fuels and engine modifications are also being tried to lower the harmful emissions. NOx is very toxic gas and is responsible for very horrible effects such as acid rain, water quality deterioration, ground level ozone, and visibility impairment. Uses of vegetable oil as fuel, water injection, exhaust gas recirculation (EGR) and after treatment technique are the basic ways to minimise the NOx. EGR technique is worldwide opted technique to reduce the NOx emission by diluting fresh charge with recirculation of some amount of exhaust gas. In this review, modelling and analysis of different types of EGR have been reported and compared. Out of them, analytical results favour the use of long route (LR) EGR over short route (SR) EGR.

Keywords: exhaust gas recirculation; EGR; exhaust emission; global warming.

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1 Introduction

In the present world uses of automobiles is excessively increased and therefore emission also crossed the level. The gasses which are exhausted from the automotive engines is a mixture of unburned fuel (i.e., hydrocarbon), the product of partial or incomplete combustion (hydrocarbon, particulate and carbon monoxide), the product of complete combustion (carbon dioxide and water vapour), products of high temperatures and pressures generated during combustion (oxides of nitrogen) and the elements of the inlet air that undergo no change during combustion (nitrogen, oxygen, carbon dioxide and water vapour). The automobile sector in India is the major sources of green house gas (GHG). It was observed that almost 14% of the total emissions are from automobiles, refer Figure 1. Other than the water vapour remaining exhaust emissions are considered harmful for environment. Therefore, the pollution control board of each country sets the upper limits for the vehicle exhaust emissions. Original equipment manufacturers (OEM) always push their research towards implementation of emission control strategies in order to fulfil the pollution norms (Reifarth, 2014).

Oxides of nitrogen (NOx) are produced when fuel is burned at a very high temperature. NOx is major pollutant responsible for many harmful diseases. The effect of NOx exposure on the respiratory system is similar to that of ozone and sulphur dioxide. NOx is generated when temperature inside the combustion chamber rises about 2000 K. Combustion chamber temperature reduction reported though many strategies [e.g., by enriching the fuel air mixture, lowering the compression ratio, spark timing control and exhaust gas recirculation (EGR)]. Exhaust EGR is a system in which exhaust gases are re-circulated inside the engine by some proportion (e.g., 5%, 10%, 15% 20%, 25% and 30%), which causes to reduction in combustion chamber temperature and which finally helps in reduction in NOx formation. Through this method, other pollutants (HC, CO and PM, etc.) level goes high because of incomplete combustion (Siju and Rathod, 2014). In order to overcome this problem, uses of catalytic convertors are preferred to reduce these emissions. Strategies used to reduce NOx emission include: injection timing retard, injection rate shaping, charge air chilling, water fuel emulsions, EGR, etc. EGR is helpful to improve engine performance at low load with reduced NOx emission. EGR is classified into two types, one is hot EGR (to circulate the exhaust gases without treatment) and another one is cooled EGR (in which exhaust gases are cooled before circulation into the engine cylinder) (Daisho, 1995). Bhaskar et al. (2013) had given a brief description and show its interest in the search for alternatives to petroleum derived fuels for diesel engines. Key driving factors are depleting fossil-fuel reserves all over the globe as well as the environmental impact of burning fossil fuels that cause pollution and global warming. Bio-diesel derived from edible oils, non-edible oils and all over the world there are different emission acceptance rule. OEMs have to satisfy the pollution...
norms specified by the pollution board of each country for new automobiles in order to get approved for sale.

**Figure 1** Sectorwise greenhouse gas emission for the year 2015–2016 (global greenhouse gas emissions data) (see online version for colours)

1.1 Nox formation mechanism

Due to the post flame combustion process inside the cylinder the temperature is already too high and in this high temperature zone, NO is formed. Zeldovich mechanism is reported for analysis of NO inside the combustion chamber (Heywood, 1988). The principal reactions at near stoichiometric air-fuel mixture governing the formation of NO from molecular nitrogen are:

\[
\begin{align*}
O + N_2 &= NO + N \\
N + O_2 &= NO + O \\
N + OH &= NO + H
\end{align*}
\]

Levendis et al. (1994) described initial rate controlled NO formation (i.e., when \([NO]/[NO_2]_e \ll 1\) when \([NO]\) denotes the molar concentration of the species and \([O_2]_e\) and \([N_2]_e\) denotes the equilibrium concentration, through this equation.

\[
\frac{d[NO]}{dt} = \left( \frac{6 \times 10^{16}}{T^{0.5}} \right) \exp \left( \frac{-69.096}{T} \right) \left[ O_2 \right]_e^{0.5} \left[ N_2 \right]_e \text{ mol s}^{-2} \text{ cm}^{3}
\]
Equation (4) is able to show NO formation rate with respect to oxygen concentration and temperature. In addition to this, cetane improving additives are also able to reduce NOx. But, reduction reported is not adequate and also these additives are expensive. Therefore, retarded injection is a good option to reduce NOx formation in diesel engines. However, drawbacks like reduced power, increased fuel consumption, higher smoke and HC emissions are associated with this. Some literatures reported use of water injection inside the engine cylinder in order to decrease the temperature inside and subsequently the NOx formation. Some issues such as water storage and engine corrosion identified with the use of this method, see Pradeep and Sharma (2007). Reifarth (2014) reported unstability of
NOx formation in combustion engines as higher temperature is available for a short while. Instead, the reactions 'freeze' as soon as the local temperature falls below 2200 K. This explains the steep decrease of the NOx formation rate during the expansion stroke in Figure 2.

If the temperatures stay below a certain level during the whole combustion process, the formation of NOx can be avoided almost completely, refer Figure 3.

2 EGR system

In the past years, EGR has been identified as the one of the most suitable option to reduce NOx formation inside combustion chamber. There are two types of EGR, one is internal EGR and another is external EGR. External EGR is achieved through recirculation of part of exhaust gas directly from the exhaust port to inlet port, whereas in internal EGR is achieved by extended negative valve overlap (NVO) during exhaust stroke by variable valve timing. Use of internal EGR is limited that other way promotes the external EGR, see Wei et al. (2012). Exhaust gases contains CO₂, N₂ etc. that replaces the fresh air intake inside the cylinder. This ultimately reduces the availability of oxygen for combustion and lower formation of NOx happened. To overcome these issues, an optimised EGR (\%) is to be identified that balance lower NOx formation without having considerable drop in performance of engine. EGR (\%) is represented as equation (2), where \( M_{\text{EGR}} \) is the mass of exhaust gas recirculated and \( M_I \) is the total mass of intake inside the cylinder (\( M_I = M_a \) (mass of air induced) + \( M_f \) (mass of fuel injected) + \( M_{\text{EGR}} \)).

\[
\text{EGR}(\%) = \frac{M_{\text{EGR}} \times 100}{M_I}
\]  

(5)

Desantes et al. (2010) used non-dispersive infrared detector (NDIR)-based CO₂ concentration measurement at the intake ([CO₂]_{intake}) and exhaust manifold ([CO₂]_{exh}) for the determination of EGR rate.

\[
\text{EGR}(\%) = \frac{[CO₂]_{\text{intake gas}} - [CO₂]_{\text{Ambient}}}{[CO₂]_{\text{Exhaust gas}} - [CO₂]_{\text{Ambient}}}
\]  

(6)

It is clear from the results reported by Desantes et al. (2010) that exhaust emission form EGR engine was lowered compared to non EGR engine emissions. But, toxic substance inside exhaust gas found unchanged however totals quantity of toxic substance emission reduced for same volumetric concentration.

Wagner et al. (2003) reported high EGR rate (nearly 44\%) and found significant drop in PM and NOx emission but fuel economy got affected significantly. Sasaki et al. (1998) conducted studies on the use of EGR in a direct injection gasoline engines and reported high fuel economy and HC emission. Kusaka et al. (2000) identified with experiments that at low loads, EGR combined with intake heating reduced the HC emission and improved thermal efficiency. With use of EGR in natural gas dual fuel diesel engine, poor engine performance reported along with more noise (Selim, 2003). Literatures Wade (1980), Needham et al. (1991), Agarwal et al. (2004), Mehta et al. (1994), Cinar et al. (2005), Dec (2009) and Gautam et al. (1999) claimed the lower NOx emission from diesel engine with higher specific fuel consumption and PM emission. EGR engines
formed more soot during combustion which remains un-oxidised. This affects the engine performance by wear of the engine parts such as piston rings, cylinder liner and bearings. It also increases the carbon deposits inside cylinder (Heywood, 1988).

Gautam et al. (1999) experimentally claimed that soot interacts with oil additives reducing and due to abrasive wear mechanism it reduced its anti-wear property. Previous to that, Nagai et al. (1983) reported study of valve-train wear in presence of soot while EGR was varied from 0 to 25%, results showed wear of cam noses while rocker arm tips found increased. Another option is cooled EGR which achieved through cooling of exhaust gases before recirculation. This phenomenon is helpful to increase volumetric efficiency of the engine. Plee et al. (1982) reported that temperature is greater responsible than the oxygen availability for NOx formation. The application of EGR adversely affects the engine durability and lubricating oil quality, (Ishiki et al., 2000; Gautam et al., 1999; Nagai et al., 1983; Aldajah et al., 2007; George et al., 2007; Singh et al., 2006).

3 EGR verses NOx

From the literatures (Agarwal et al., 2011; Benson and Whitehouse, 2013; Lavoie et al., 1970), it is noted that phenomenon of formation of NO is quite different from formation of HC and CO. NO formation is due to proliferation of mixed combustion, concentration distribution of flame and heat transfer. The N2 hardly exist in the fuel but in the air intake, which reacts with free oxygen at a very high temperature of 1,800–2,000 K. It forms NO ini combustion chamber in post flame combustion process in high temperature zone. Abd-Alla et al. (2002) mentioned that EGR also involves recirculation of CO2 inside the combustion chamber and its excess exerts three effects when available during combustion:

a Thermal effect: It increases heat capacity of the oxidiser and flame temperature is reduced by this.

b Dilution effect: EGR replaces the fresh charge and so the availability of oxygen during the combustion process and which in turn reduces collision frequency.

c Chemical effect: CO2 participates in combustion being an active chemical compound.

Figure 4 Increase in volume occupied by spray flame with use of EGR (see online version for colours)
Engine tests have demonstrated that NOx is greatly suppressed when the O\textsubscript{2} concentration in combustion chamber is reduced. Figure 4 express that reduction in O\textsubscript{2} concentration reduction in the NOx formation. Refer Figure 4(b) it is evident that for a given amount of fuel, this larger area contains not only stoichiometric mixture but also an additional quantity of CO\textsubscript{2}, H\textsubscript{2}O and N\textsubscript{2}. These additional gases absorb the energy released by the combustion, leading to lower flame temperature and then lower NOx generation, see Abd-Alla et al. (2002) and Ladommatos et al. (1998).

In modern diesel engines, the combination of the former quantities normally comprise more than 99% of the exhaust, while the latter combination, the pollutants accounts for less than 1% in quantity. Now, the thing is to optimise the performance and pollution by thermodynamic properties and oxygen concentrations. Target is to keep power and efficiency high and keeping NOx formation at low.

Figure 5 NOx reduction versus synthetic EGR rate

As discussed earlier, load levels of a diesel engines is a very important parameter as low load EGR shows promising results as compared to high load EGR. It is because exhaust composition and temperature are affected by load levels of diesel engines. In CI engine, fuelling rate in diesel engines is responsible for setting load levels whereas in SI engines air-fuel mixture charging rate. Without EGR, diesel engines produce only 5% O\textsubscript{2} containing exhaust at full load and 20% at idling. So, it is evident that NOx reduction by EGR also varies with load. Heat capacity of the cylinder charge increases which ultimately reduce the flame temperature during combustion. Results revealed that high % of EGR are to be preferred during low level loads and vice versa (Zheng et al., 2004). As shown in Figure 5, tests were carried out in a synthetic atmosphere equivalent to thoroughly cooled EGR. The temperature at intake maintained at 30°C and CO\textsubscript{2} definition discussed previously. Test results reported in Figure 6 are obtained using EGR cooler to keep outlet temperature below the 80°C. It also compares the hot EGR and
enhanced cooled EGR showing favour to cooled EGR. From the literature (Zheng et al., 2004), it is notified that diesel engines emit more smoke because of less availability of oxygen at higher load levels.

**Figure 6**  Comparison between cooled and hot EGR

![Comparison between cooled and hot EGR](source: Zheng et al. (2004))

**Figure 7**  Trade-off between exhaust NOx and opacity (smoke) when hot EGR is applied

![Trade-off between exhaust NOx and opacity (smoke) when hot EGR is applied](source: Zheng et al. (2004))

During testing the results are shows high amount of EGR when the load is low while at high load it indicates low or no EGR. At full load EGR rate is delay but PM formation is increased. However as generation of NOx is extreme at full load, extended fuel injection retarding could be implemented in lieu of EGR (Murayama et al., 1995).
4 Comparison between the different EGR architectures

Different classifications of EGR have been already discussed in previous section of this literature. There are some more setups have been tried so far, out of which short route (SR) EGR and long route (LR) EGR are further types. In LR system, the pressure drop across the air intake causes the EGR possible. While in SR system, the positive pressure is developed across the EGR circuit. A detailed description of the different setups to achieve LR and SR EGR is given in literature by Maiboom et al. (2009). From results, it is reported that LR EGR is capable to recirculate higher density of exhaust gases keeping higher fresh air mass flow and thus resulted in a better soot-NOx trade off, see Maiboom et al. (2009).

Figure 8  Comparison of experimental ‘trade-off’ NOx – soot with both short route (SR) and long route (LR) for the 3,000 rpm/10 bar BMEP engine (see online version for colours)

![Graph showing comparison of NOx and soot](image)

*Source: Maiboom et al. (2009)*

Figure 9 shows the individual EGR rates for each of the 4 cylinders. EGR rates have calculated through a CFD analysis for the SR EGR. It helped in the findings of differences among the cylinders which could further lead to combustion stability, PM and NOx emissions (Maiboom et al., 2009).

In addition to above, there are numerous advantages of LR EGR system. It is capable to reduce pumping work and helpful to avoid the need to operate VGT at closer rack positions. However, if the flow resistance of the LR EGR system is high, the throttle valve in the intake system must be partially closed, which can be used to increase the pressure gradient between the exhaust and intake systems and therefore the recirculated gas rate and the pumping work therefore deteriorates dramatically, as shown in Figure 10. As reported previously, LR layout leads to lower pumping losses, as long as the throttle
valve is completely open. But to achieve higher EGR rate, use of SR system is advantageous over LR because of higher pumping work would be required in LR system. So, DL system could offer a better solution in this case by providing additional path without using throttle valve to increase the pressure drop.

**Figure 9** EGR ratio distribution in the different cylinders with a short route EGR system, resulting from computational fluid analysis (CFD) analysis (see online version for colours)

In the LR system EGR, specific fuel consumption is also advantageous for a certain NOx specific emission level. A brake specific fuel consumption (BSFC) verses Brake Specific NOx trade off is shown in Figure 11. Compared to Figure 13, a different trade off is achieved in Figure 12. In Figure 13, it shows that the EGR rate is constantly increased with the EGR rate, an abrupt change in slope is noticed in the LR trend for a 25% EGR rate. This experience is possibly due to need to introduce throttling effect to further increase the EGR rate since the pressure gradient for this LR EGR would not be sufficient to obtain high EGR flows. As shown in Figure 12, indicated thermal efficiency drops for LR EGR at EGR rate more than 25%. Tables 1 and 2 show turbocharger data for different EGR rate operating conditions. It is clear for the data that effects achieved with higher compressor and turbine efficiencies are completely cancelled because of higher power required for compressor and higher mass flow rate is to be compressed that resulted almost identical backpressure values (Millo et al., 2012).

In case of transient conditions, LR EGR option show poor response due to high volume of system. But dual loop (DL) EGR systems as combination of LR and SR EGR is helpful in transient conditions by offering improved performance, however, it increases complexity of system that could be worked out with use of numerical simulation as a virtual test bench to control tuning and calibration.
**Figure 10** Pumping loop losses for the SR and LR EGR systems (see online version for colours)

![Diagram showing pumping loop losses for SR and LR EGR systems.](image)

Note: 1,500 rpm/2 bar brake mean effective pressure (BMEP).

*Source:* Maiboom et al. (2009)

**Figure 11** Comparison between different EGR layouts (SR and LR): NOx emissions vs. BSFC trade-off @ 1,500 rpm/2 bar BMEP (see online version for colours)

![Diagram showing comparison between different EGR layouts.](image)

*Source:* Maiboom et al. (2009)
**Figure 12**  Comparison between different EGR layouts (SR and LR): engine indicated efficiency vs. EGR rate @ 1,500 rpm/2 bar BMEP (see online version for colours)

Source: Millo et al. (2012)

**Figure 13**  Comparison between different EGR layouts (SR and LR): BSFC vs. EGR rate @ 1,500 rpm/2 bar BMEP (see online version for colours)

Source: Maiboom et al. (2009)
Figure 14 shows the simulation of a load step transient for the 1,500 rpm engine operating point: as can be seen, the EGR ratio variation for the same electronic control unit (ECU) request is faster for the SR configuration, due to the ratio between the LR circuit volume and the SR circuit volume, which are about 4%.

**Figure 14**  Short Route EGR vs. long route EGR for a step load transient (1,500 rpm) (see online version for colours)

![Figure 14](image1)

*Source:* Maiboom et al. (2009)

**Figure 15**  Comparison between different EGR layouts (see online version for colours)

![Figure 15](image2)

*Note:* SR, LR and DL with 20% SR/80% LR.

*Source:* Maiboom et al. (2009)
Table 1 showed the comparison of different performance parameters of turbine and compressor at various EGR rate in steps of 10% till 50% for short route (SR) EGR. Similarly, Table 2 reported comparison of the performance parameters of turbine and compressor for long route (LR) EGR. Comparison shows high efficiency of turbine and compressor using LR than SR EGR at all %rate of EGR. Power from turbine is higher for LR EGR in comparison with SR EGR.

Table 1  Turbocharger operating conditions for the 1,500 rpm/2 bar BMEP engine operating point for different EGR rates (SR EGR)

<table>
<thead>
<tr>
<th>EGR rate (%)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>62.8</td>
<td>61.0</td>
<td>57.2</td>
<td>53.6</td>
<td>50.8</td>
<td>45.0</td>
</tr>
<tr>
<td>Power (kW)</td>
<td>0.685</td>
<td>0.617</td>
<td>0.54</td>
<td>0.464</td>
<td>0.389</td>
<td>0.323</td>
</tr>
<tr>
<td>Mass flow rate (kg/s)</td>
<td>0.03</td>
<td>0.027</td>
<td>0.023</td>
<td>0.02</td>
<td>0.017</td>
<td>0.014</td>
</tr>
<tr>
<td>Back press/boost press. ratio (-)</td>
<td>1.16</td>
<td>1.16</td>
<td>1.17</td>
<td>1.19</td>
<td>1.19</td>
<td>1.23</td>
</tr>
<tr>
<td>Rack position (%)</td>
<td>22.2</td>
<td>18.9</td>
<td>16</td>
<td>13.4</td>
<td>11</td>
<td>3.5</td>
</tr>
<tr>
<td>Compressor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>52</td>
<td>51.3</td>
<td>50.5</td>
<td>49.8</td>
<td>49.2</td>
<td>48.9</td>
</tr>
<tr>
<td>Specific work (kJ/kg)</td>
<td>23.25</td>
<td>23.54</td>
<td>23.5</td>
<td>23.46</td>
<td>23.4</td>
<td>23.94</td>
</tr>
<tr>
<td>Mass flow rate (kg/s)</td>
<td>0.029</td>
<td>0.026</td>
<td>0.023</td>
<td>0.02</td>
<td>0.017</td>
<td>0.014</td>
</tr>
<tr>
<td>Inlet temperature (K)</td>
<td>296</td>
<td>296</td>
<td>296</td>
<td>296</td>
<td>296</td>
<td>296</td>
</tr>
</tbody>
</table>

Source: Maiboom (2009)

Table 2 Turbocharger operating conditions for the 1,500 rpm/2 bar BMEP engine operating point for different EGR rates (LR EGR)

<table>
<thead>
<tr>
<th>EGR rate (%)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>62.8</td>
<td>62.6</td>
<td>62.3</td>
<td>62</td>
<td>60.2</td>
<td>58.2</td>
</tr>
<tr>
<td>Power (kW)</td>
<td>0.685</td>
<td>0.698</td>
<td>0.713</td>
<td>0.73</td>
<td>0.771</td>
<td>0.817</td>
</tr>
<tr>
<td>Mass flow rate (kg/s)</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.029</td>
</tr>
<tr>
<td>Back press/boost press. ratio (-)</td>
<td>1.16</td>
<td>1.16</td>
<td>1.17</td>
<td>1.17</td>
<td>1.18</td>
<td>1.21</td>
</tr>
<tr>
<td>Rack position (%)</td>
<td>22.2</td>
<td>21.8</td>
<td>21.2</td>
<td>20.4</td>
<td>18.9</td>
<td>17.6</td>
</tr>
<tr>
<td>Compressor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>52</td>
<td>52.1</td>
<td>52.2</td>
<td>52.5</td>
<td>53.4</td>
<td>54.5</td>
</tr>
<tr>
<td>Specific work (kJ/kg)</td>
<td>23.25</td>
<td>23.74</td>
<td>24.31</td>
<td>24.93</td>
<td>26.45</td>
<td>28.1</td>
</tr>
<tr>
<td>Mass flow rate (kg/s)</td>
<td>0.029</td>
<td>0.029</td>
<td>0.029</td>
<td>0.029</td>
<td>0.029</td>
<td>0.029</td>
</tr>
<tr>
<td>Inlet temperature (K)</td>
<td>296</td>
<td>302</td>
<td>308</td>
<td>314</td>
<td>319</td>
<td>324</td>
</tr>
</tbody>
</table>

Source: Maiboom (2009)
Figure 16  Comparison between the SR and LR EGR systems for the simulated exhaust NOx emissions over the first 60 s of the extra urban driving cycle (EUDC) (see online version for colours)

Source: Millo et al. (2012)

Figure 17  Comparison between the SR and LR mixed loop (see online version for colours)

Source: Millo et al. (2012)
Growing by gradual increases of NOx emissions, compared with the short route (SR) system (buy reducing up to 16% for the considered cycle segment). In spite of that, the slow response of the system causes some unfavourable nitrogen oxides overshoots, throughout the acceleration ramps, as can be shown in the Figure 16. Therefore to overcome this drawback use of a DL system possibly can chosen, which could increase the response of the system. On the other than the LR behaviour maintaining impressive advantages during steady state or gradual varying operation conditions, expected to lower the consumption manifold temperature.

An impressive reduction in the NOx overshoots during velocity ramps can be discovered in Figure 16 and a further cumulative NOx emissions benefit of up to 4% for the considered cycle segment can be noticed in Figure 17, thus demonstrating the potential of the Dual Loop solution.

Zamboni et al. (2016) experimentally investigated hybrid EGR with turbocharger at part load conditions and reported 58-66% NOx reductions. Svensson et al. (2017) worked out the different turbocharger configurations for a heavy duty partially premixed combustion engine. Results showed that two-stage turbocharger was able to give the highest load over the whole speed range, whereas two single-stage turbochargers achieved 18.9 bar and 20.7 bar respectively. A study made by Khalef et al. (2016) showed influence of combination of EGR and turbocharger on engine efficiency and emissions.

5 Conclusions

This paper reviewed the past work carried out on the use of EGR and its various configurations to lower the NOx emissions from the internal combustion engines. The consequences and advantages discussed with taking concern of both performance of engines as well as emission from engines. It is evident from the research made is that use of LR EGR is preferred over other EGR setups but in transient conditions DL EGR is advantageous. The experimental and numerical analysis were discussed in this review paper for reduction of NOx emissions of different EGR structures for diesel engines to be assessed. An optimised EGR% based upon transient conditions is yet to be set so that EGR could be implemented in the passenger cars to achieve its real effect out from the boundaries of research.

References


A modelling and analysis of exhaust gas recirculation system


