JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Effect of EGR on the Exhaust Gas Temperature and Exhaust opacity in Diesel Engines

Swati Mishra[1] , Dr. Narendra N Wadaskar[2] & Prof. Avinash R Mankar[3]
[1]Research Scholar, [2,3] Professor, Department of Mechanical Engineering, GNIT, Nagpur

Abstract. In diesel engines, NOx formation is a highly temperature-dependent phenomenon and takes place when the temperature in the combustion chamber exceeds 2000 K. Therefore, in order to reduce NOx emissions in the exhaust, it is necessary to keep peak combustion temperatures under control.

One simple way of reducing the NOx emission of a diesel engine is by late injec- tion of fuel into the combustion chamber. This technique is effective but increases fuel consumption by 10–15%, which necessitates the use of more effective NOx reduction techniques like exhaust gas recirculation (EGR). Re-circulating part of the exhaust gas helps in reducing NOx, but appreciable particulate emissions are observed at high loads, hence there is a trade-off between NOx and smoke emis- sion. To get maximum benefit from this trade-off, a particulate trap may be usedto reduce the amount of unburnt particulates in EGR, which in turn reduce the particulate emission also.

An experimental investigation was conducted to observe the effect of exhaust gas re-circulation on the exhaust gas temperatures and exhaust opacity. The experi- mental setup for the proposed experiments was developed on a two-cylinder, direct injection, air-cooled, compression ignition engine. A matrix of experiments was conducted for observing the effect of different quantities of EGR on exhaust gastemperatures and opacity.

Keywords. Diesel engine; EGR; NOx; pollution.

1. Introduction

Over recent past years, stringent emission legislations have been imposed on NOx, smoke and particulate emissions emitted from automotive diesel engines world wide. Diesel engines are typically characterized by low fuel consumption and very low CO emissions. However, the NOx emissions from diesel engines still remain high. Hence, in order to meet the envi- ronmental legislations, it is highly desirable to reduce the amount of NOx in the exhaust gas.

Diesel engines are predominantly used to drive tractors, heavy lorries and trucks. Owing to their low fuel consumption, they have become increasingly attractive for smaller lorries and passenger cars also. But higher NOx emissions from diesel engine remain a major problemin the pollution aspect.

For reducing vehicular emissions, baseline technologies are being used which include direct injection, turbo-charging, air-to-air inter-cooling, combustion optimization with and without swirl support, multi-valve cylinder head, advanced high pressure injection system i.e. split injection or rate shaping, electronic management system, lube oil consumption control etc. However, technologies like exhaust gas recirculation (EGR), soot traps and exhaust gas after-treatment are essential to cater to the challenges posed by increasingly stringent environmental emission legislations.

1.1 Mechanism of NOx formation

A major hurdle in understanding the mechanism of formation and controlling its emission is that combustion is highly heterogeneous and transient in diesel engines.

While NO and NO_2 are lumped together as NOx, there are some distinctive differences between these two pollutants. NO is a colourless and odourless gas, while NO_2 is a reddish-brown gas with pungent odour. Both gases are considered toxic, but NO_2 has a level of toxicity5 times greater than that of NO. Although NO_2 is largely formed from oxidation of NO, attention has been given on how NO can be controlled before and after combustion (Levendis *et al* 1994).

NO is formed during the post flame combustion process in a high temperature region. The most widely accepted mechanism was suggested by Zeldovich (Heywood 1988). The principal source of NO formation is the oxidation of the nitrogen present in atmospheric air. The nitric oxide formation chain reactions are initiated by atomic oxygen, which forms from the dissociation of oxygen molecules at the high temperatures reached during the combustion process. The principal reactions governing the formation of NO from molecular nitrogen are,

$$N_2 + O \rightarrow NO + N, N + O_2 \rightarrow NO$$
$$+ O, N + OH \rightarrow NO + H.$$

Chemical equilibrium consideration indicates that for burnt gases at typical flame tempera-tures, NO_2/NO ratios should be negligibly small. While experimental data show that this is true for spark ignition engines, in diesels, NO_2 can be 10 to 30% of total exhaust emissionsof oxides of nitrogen. A plausible mechanism for the persistence of NO_2 is as follows. NO formed in the flame zone can be rapidly converted to NO_2 via reactions such as

$$NO + HO_2 \rightarrow NO_2 + OH.$$

Subsequently, conversion of this NO_2 to NO occurs via

$$NO_2 + O \rightarrow NO + O_2,$$

unless the NO_2 formed in the flame is quenched by mixing with cooler fluid. This explanation is consistent with the highest NO_2/NO ratio occurring at high load in diesels, when cooler regions which could quench the conversion back to NO are widespread wood 1988).

The local atomic oxygen concentration depends on molecular oxygen concentration as well as local temperatures. Formation of NOx is almost absent at temperatures below 2000 K. Hence any technique, that can keep the instantaneous local temperature in the combustion chamber below 2000 K, will be able to reduce NOx formation.

2. EGR technique for NOx reduction

EGR is a useful technique for reducing NOx formation in the combustion chamber. Exhaust consists of CO_2, N_2 and water vapours mainly. When a part of this exhaust gas is re-circulated to the cylinder, it acts as diluent to the combusting mixture. This also reduces the O_2 concentration in the combustion chamber. The specific heat of the EGR is much higher than fresh air, hence EGR increases the heat capacity (specific heat) of the intake charge, thus decreasing the temperature rise for the same heat release in the combustion chamber.

$$\% \text{ EGR} = \frac{\text{Volume of EGR}}{\text{Total intake charge into the cyclinder}} \text{ X } 100$$

Another way to define the EGR ratio is by the use of CO_2 concentration (Baert *et al* 1999),

$$\text{EGR ratio} = \frac{[CO_2]_{intake} - [CO_2]_{ambient}}{[CO_2]_{exhaust} - [CO_2]_{ambient}}.$$

Three popular explanations for the effect of EGR on NOx 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. 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. According to the dilution theory, the effect of EGR on NOx is caused by increasing amounts of inert gases in the mixture, which reduces the adiabatic flame temperature (Pierpont *et al* 1995).

At high loads, it is difficult to employ EGR due to deterioration in diffusion combustion and this may result in an excessive increase in smoke and particulate emissions. At low loads, unburnt hydrocarbons contained in the EGR would possibly re-burn in the mixture, leading to lower unburnt fuel in the exhaust and thus improved brake thermal efficiency. Apart from this, hot EGR would raise the intake charge temperature, thereby influencing combustion and exhaust emissions.

With the use of EGR, there is a trade-off between reduction in NOx and increase in soot, CO and unburnt hydrocarbons. A large number of studies have been conducted to investigate this. It is indicated that for more than 50% EGR, particulate emissions increase significantly, and therefore use of a particulate trap is recommended. The change in oxygen concentration causes change in the structure of the flame and hence changes the duration of combustion. It is suggested that flame temperature reduction is the most important factor influencing NO formation. Figure 1 shows the reduction in NOx emission due to EGR at different loads. Implementa- tion of EGR in diesel engines has problems like (a) increased soot emission, (b) introduction of particulate matter into the engine cylinders. When the engine components come into con- tact with high velocity soot particulates, particulate abrasion may occur. Sulphuric acid and condensed water in EGR also cause corrosion. Some studies have detected damage on the

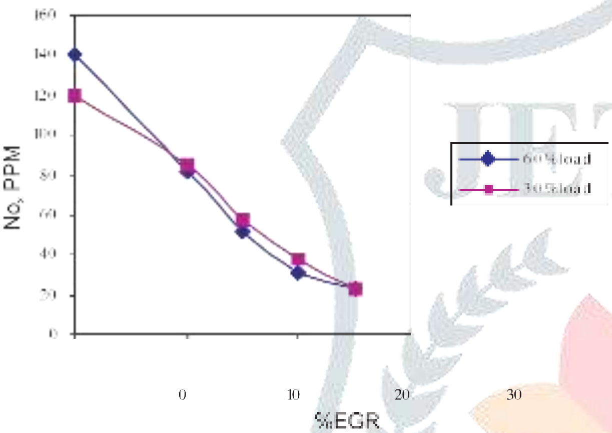

Figure 1. Effect of EGR on NOx (Mehta *et al* 1994)

cylinder walls due to the reduction in the oil's lubrication capacity, which is hampered due to the mixing of soot carried with the particulate laden recirculated exhaust gas. This necessitates the use of an efficient particular trap (Mehta *et al* 1994).

Studies have shown that EGR coupled with a high collection-efficiency particulate trap, controls smoke, unburnt hydrocarbon and NOx emissions simultaneously. The particulate trap, however, needs to be regenerated since its pores get clogged by the trapped soot particles. Clogged soot traps increase backpressure to the engine exhaust, thus affecting engine performance also. These traps need to be regenerated from time to time using thermal or aerodynamic or electrostatic regeneration techniques. Other methods of reducing the particulate emission from diesel engines include multiple injections, supercharging and higher fuel injection pressure etc. The highest attention is currently being paid to two self-regenerating systems: fuel additive-supported regeneration by using cerium- or iron-based additives, and a continuous regeneration trap (CRT) using sulphur-free diesel fuel (Zelenka *et al* 1998).

During the last 20 years, plenty of research work has been done on EGR and its effects on the engine performance in terms of fuel efficiency, volumetric efficiency, power generated etc. These studies have been carried out at various loads, engine speed and variable engine parameters like temperature and pressure, compression ratio etc.

3. Classification of EGR systems

Various EGR systems have been classified on the basis of EGR temperature, configuration and pressure.

3.1 *Classification based on temperature*

(i) *Hot EGR:* Exhaust gas is recirculated without being cooled, resulting in increased intake charge temperature.

(ii) *Fully cooled EGR:* Exhaust gas is fully cooled before mixing with fresh in take air using a water-cooled heat exchanger. In this case, the moisture present in the exhaust gas may condense and the resulting water droplets may cause undesirable effects inside the engine cylinder.

(iii) *Partly cooled EGR:* To avoid water condensation, the temperature of the exhaust gas is kept just above its dew point temperature.

3.2 *Classification based on configuration*

(i) *Long route system (LR):* In an LR system the pressure drop across the air intake and the stagnation pressure in the exhaust gas stream make the EGR possible. The exhaust gas velocity creates a small stagnation pressure, which in combination with low pressure after the intake air, gives rise to a pressure difference to accomplish EGR across the entire torque/speed envelop of the engine.

(ii) *Short route system (SR):* These systems differed mainly in the method used to set up a positive pressure difference across the EGR circuit.

Another way of controlling the EGR-rate is to use variable nozzle turbine (VNT). Most of the VNT systems have single entrance, which reduce the efficiency of the system by exhaust pulse separation. Cooled EGR should be supplied effectively. Lundquist and others used a variable venturi, in which EGR-injector was allowed to move axially, thus varying the critical area was used (Lundquist *et al* 2000).

3.3 *Classification based on pressure*

Two different routes for EGR, namely low-pressure and high-pressure route systems may be used (Kohketsu *et al* 1997).

(i) *Low pressure route system:* The passage for EGR is provided from downstream of the turbine to the upstream side of the compressor.

It is found that by using the low pressure route method, EGR is possible up to a high load region, with significant reduction in NO_x. However, some problems occur, which influence durability, prohibitionary high compressor outlet temperature and intercooler clogging.

(ii) *High pressure route system:* The EGR is passed from upstream of the turbine to down-stream of the compressor.

In the high pressure route EGR method, although EGR is possible in the high load regions, the excess air ratio decreases and fuel consumption increases remarkably.

4. Experimental setup

An experiment with an aim to measure the effect of surge (modified section) of EGR pipes on engine emissions of a diesel engine is carried out.

Table 1. Engine specifications

Cylinders	4
Bore	94 mm
Stroke	115 mm
Compression ratio	18.5
Naturally aspirated	
4 stroke engine	
DI engine	
Water cooled engine	

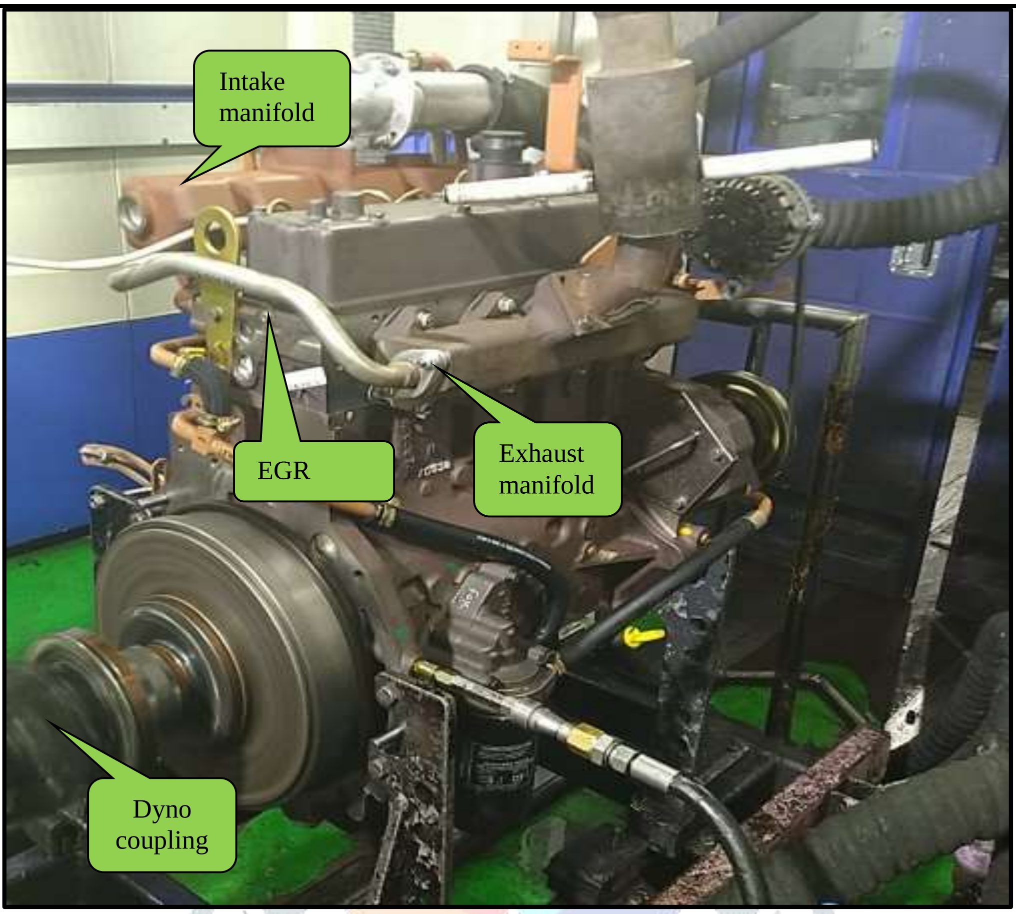

Figure 2. Experimental setup

5. Results and discussion

5.1. Analysis result

1. Pipe 1(Original)

Initial condition

Inlet temperature- 873 Kelvin

Figure 3. Analysis of pipe 1 original

Temperature conditions at

i.	Inlet	873 Kelvin
ii.	Outlet	436 Kelvin

2. Pipe 1(Modified)

Initial condition

Inlet temperature- 873 Kelvin

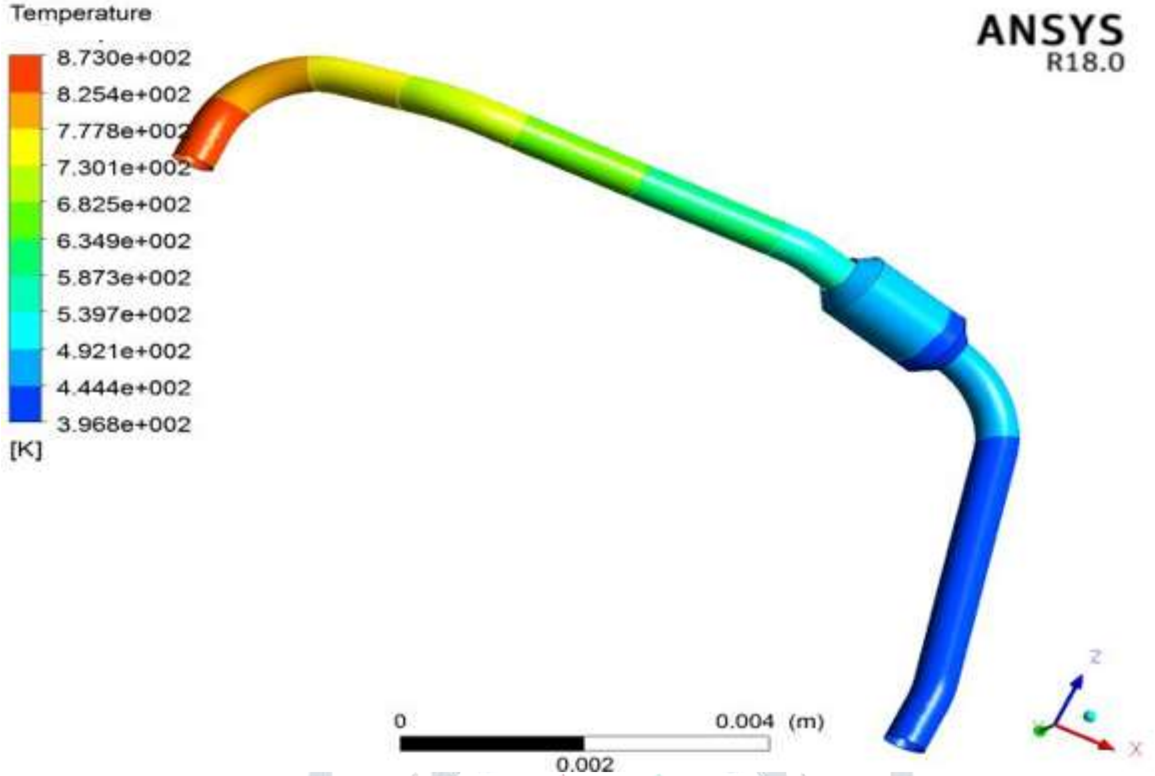

Figure 4. Analysis of pipe 1 modified

Temperature conditions at

i. Inlet 873 Kelvin

ii. Outlet 396 Kelvin

Table 2. Analysis results for pipe 1

Pipe	Inlet Temperature (Kelvin)	Outlet Temperature (Kelvin)
Original	873	436
Modified	873	396
Difference	0	40

Temperature difference found at outlet of pipe 1 with and without surge is 40°C

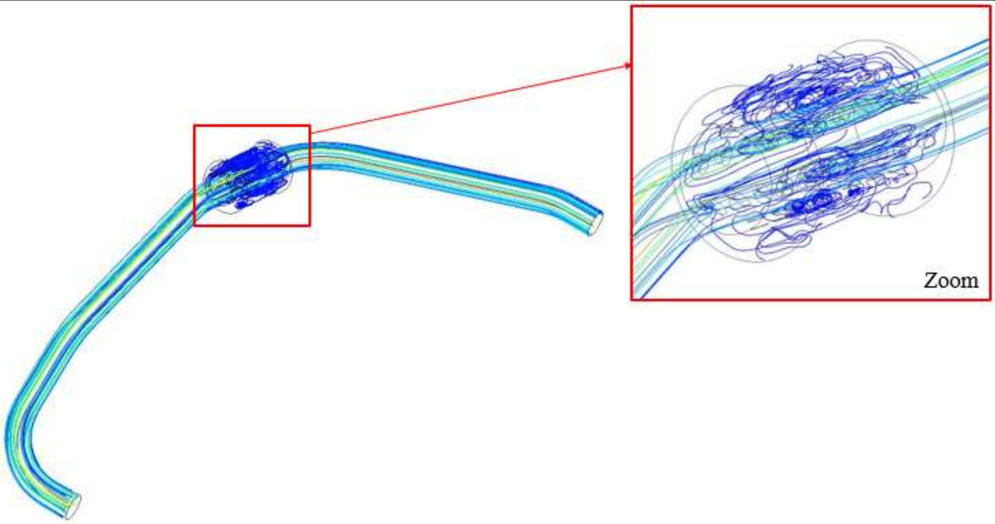

Figure 5. Flow analysis of pipe 1 modified

Modification in the pipe i.e. surge addition shows the flow as shown in the above figure. Gas passes through the wholes and some of it gets stored, due to this heat dissipation rate is increased. Hence, gases at the other end has lower temperature as compared to original pipe.

3. Pipe 2 (Original)

   Inlet temperature conditions defined as 440 Kelvin as temperature at outlet found to be 436 kelvin

Inlet temperature- 440 Kelvin

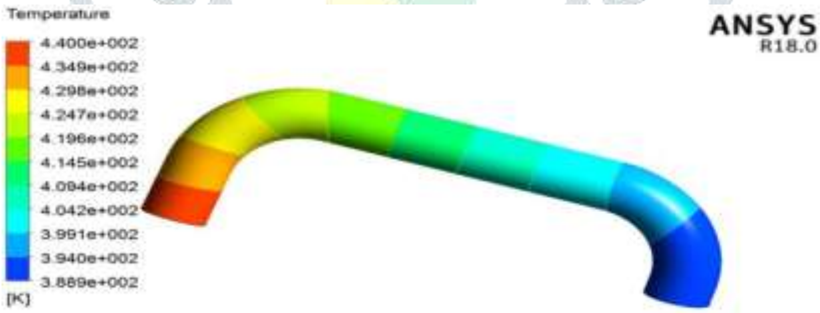

Figure 6. Analysis of pipe 2 original

Temperature conditions at

i.	Inlet	440 Kelvin
ii.	Outlet	389 Kelvin

4. Pipe 2 (Modified)

Inlet temperature- 440 Kelvin

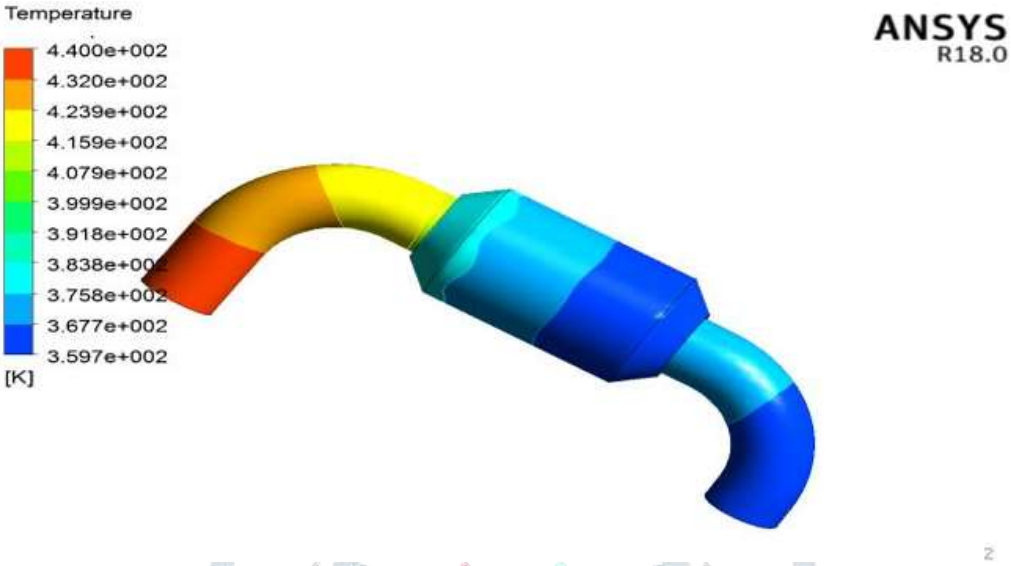

Figure 7. Analysis of pipe 2 modified

Temperature conditions at

i. Inlet 440 Kelvin
ii. Outlet 358 Kelvin

Comparison

Table 3. Analysis results for pipe 2

Pipe	Inlet Temperature (Kelvin)	Outlet Temperature (Kelvin)
Original	440	389
Modified	440	360
Difference	0	29

Temperature difference found at outlet of pipe 2 with and without surge is 29^{o}C

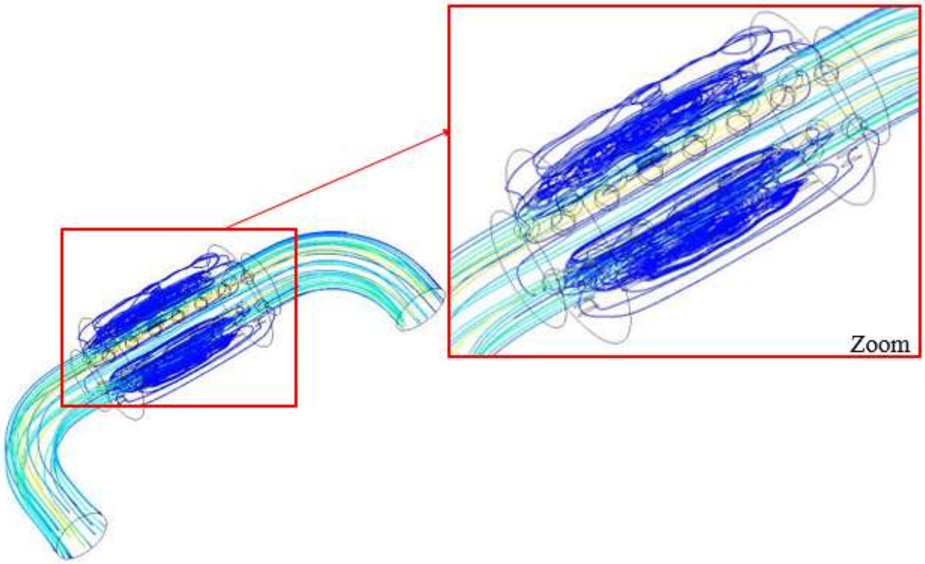

Figure 8. Flow analysis of pipe 2 modified

Modification in the pipe i.e. surge addition shows the flow as shown in the above figure. Gas passes through the wholes and some of it gets stored, due to this heat dissipation rate is increased. Hence, gases at the other end has lower temperature as compared to original pipe.

Conclusion

1. CFD analysis of pipes shows following results:
   a. Temperature difference obtained for pipe 1 (original and modified) is 40 degrees
   b. Temperature difference obtained for pipe 2 (original and modified) is 29 degrees

   By adding surge (modification) to original pipe, heat dissipation increased. This led to decrease in the temperature of exhaust gas at the intake manifold and increased the heat absorption of burnt gas.

   Consequently lowering the combustion temperature and less NOx formation.

2. Experimental setup
   Experiment performed in the emission test bed on 4DI Diesel engine for testing emissions from engine before and after modification shows that

   a. NOx emission reduced
   b. Other pollutants emissions increased.

   Thus slight modification in the pipe has reduced NOx emissions.

   By controlling the temperature of the exhaust gas at the intake it is possible to reduce it further.

   Using the modified pipe, intercooler can be eliminated which will reduce cost.

References

Baert R S G, Beckman D E, Veen A 1999 Efficient EGR technology for future HD diesel engine emission targets. SAE 1999-01-0837

Heywood J B 1988 Pollutant formation and control. Internal combustion engine fundamentals Int. edn (New York: Mc-Graw Hill) pp 572–577

Kohketsu S, Mori K, Sakai K, Hakozaki T 1997 EGR technologies for a turbocharged and inter-cooled heavy-duty diesel engine. SAE 970347

Levendis Y A, Pavalatos I, Abrams R F 1994 Control of diesel soot hydrocarbon and NOx emissions with a particular trap. SAE 940460

Lundquist U, Smedler G, Stalhammar P 2000 A comparison between different EGR systems for HD diesel engines and their effects on performance, fuel consumption and emissions. SAE 2000-01- 0226

Mehta S, Oey F, Sumbung C L, Levendis Y A 1994 An aerodynamically regenerated diesel particulate trap with a flow-through soot incinerator section. SAE 940461

Pierpont D A, Montgomery D T, Reitz R D 1995 Reducing particulate and NOx using multiple injections and EGR in a D. I. diesel. SAE 950217

Sher E 1998 Motor vehicle emissions control: Past achievements, future prospects. Handbook of air pollution from IC engines pollutant formation and control (San Diego, CA: Academic Press) pp 9–10

Stearns R F, Johnson R R, Jackson R M, Larson C A 1951 Derivation of flow equations. Flow measurements with orifice meters (Princeton,NJ : D V N Com.) p-4

Zelenka P, Aufinger H, Reczek W, Cartellieri W 1998 Cooled EGR–A technology for future efficient HD diesels. SAE 980190