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# Improving Engine Performance through Better Distribution of EGR Gases

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**ABSTRACT**

**Nitrogen oxides (NOx) contribute to a wide range of environmental effects including the formation of acid rain and destroy ozone layer. In-cylinder high temperature flame and high oxygen concentration are the parameters which boost the NOx emissions. Exhaust Gas Recirculation (EGR) system is a very effective way for reducing NOx emissions from a diesel engine. The objective of present work was to improve while reducing emissions improving the engine performance, NOx emissions. It was suspected that non-uniform distribution of EGR to individual cylinders was the cause for the higher than expected NOx. In order to verify this, EGR and air distribute between the runners was simulated through numerical means for a 4-cylinder Direct Injection (DI) turbocharged diesel engine. One dimensional gas dynamic flow analysis has been carried out for an existing engine with EGR and without EGR by using Ricardo WAVE and VECTIS software to assess the distribution of EGR gases in each runner. Based on the results, geometrical changes have been done to improve uniformity in distribution of EGR gases with the intension to reduce NOx emissions and improve engine performance. Eight different cases were studied by changing EGR connecting position on the intake manifold.**

**Keywords— Ricardo WAVE,VECTIS, EGR**

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## I. INTRODUCTION

Diesel engines are used for bulk movement of goods, powering stationary/ mobile equipment, and to generate electricity more economically than any other device in this size range. Better fuel economy and higher power with lower maintenance cost has increased the popularity of diesel engine vehicles. Diesel engines have high thermal efficiencies resulting from the high compression ratio and fuel lean operation. Diesel engines are assumed as a good alternative to gasoline engines because they produce lower amount of emissions. On the other hand, higher emissions of Oxides of Nitrogen ($NO_x$) have been noticed as major problems. Exhaust Gas Recirculation (EGR) is one of technique that has been developed to reduce emissions of Oxides of Nitrogen ($NO_x$). In this method a percentage of exhaust gases is recirculated to the intake manifold. The application of EGR requires the delivery of equal amounts of EGR to each cylinder. Moreover EGR systems lead to the unequal distribution of exhaust gases from cylinder to cylinder. If the gas recirculation system is not carefully employed significant reduction on engine power, increase in fuel consumption and other pollutants may result.

## II. MODEL CONSTRUCTION

Model construction is a very critical part in the project as the results are highly dependent on the model geometry and dimensions of the engine. This chapter starts with1D model generation of diesel engine. A Ricardo WAVE 1D model is created for a diesel engine with EGR and without EGR for the stock engine. Further CFD analysis using Ricardo VECTIS is carried out to the study the flow behaviour.

A.Modelling and analysis in Ricardo WAVE

WAVE is a computer aided engineering code developed by Ricardo to analysemthe dynamics of pressure waves, mass flows and energy losses in ducts, plenum and the mainfold of various systems and machines

WAVE provides a fully integrated treatment of time dependent fluid dynamics and thermodynamics by means of a one dimensional formulation.

In addition, WAVE provides a completely coupled interface to many CFD codes which allows various system components with complex geometry. Building a WAVE model from the ground up is best done in three distinct steps.

- Collection of data required for WAVE model
- Data preparation.
- Construction of the model in WAVE-build.

Ricardo WAVE provides a quick calculation of the fundamental physical and mathematical models. The results are only as good as the inputs and assumptions made while preparing the system. Hence data regarding every systemof the engine was collected along with the geometric details of the system.

B. Collection of data required for WAVE model.

Before model construction a wide range of the data collection is required relating the system to be simulated. The type of data required for the engine modeling was collected as geometric data, engine data and operating parameters.

a.Geometric data.

For modeling the engine the dimensions of the air were taken.

b. Engine data

Engine data includes all the dimensions and characteristics associated with the actual engine. Data collection includes the cylinder bore and stroke, connecting rod length, wrist pin offset, compression ratio, firing order and timing, mechanical friction details, valve diameters, valve timing, etc

c.Operating parameters

Operating parameters refers to the condition at which the simulation will be carried out. Inlet and exhaust wall temperatures, engine operating speed, ambient condition and combustion data are the few operating parameters required.

d. Data preparation

In this phase a rough outline of the real system model was sketched, including all the bends conjugated sections and perforates in the intake manifold and exhaust manifolds. This helps to organize how the geometry of the real system is going to be split up and modeled.

C. Construction of the model in the WAVE-build

WAVE-build is the pre-processor used to build the geometric model and provides all the input data for the physical model required to perform a WAVE analysis. WAVE consists of a canvas onto which a number of basic building blocks representing the geometry of the model are placed and edited so that the geometry accurately represents the real system. Thus a WAVE model was created through WAVE-build and is simulated to obtain the performance parameter of the engine.

a. Construction of the naturally aspirated diesel engine 1D wave model.

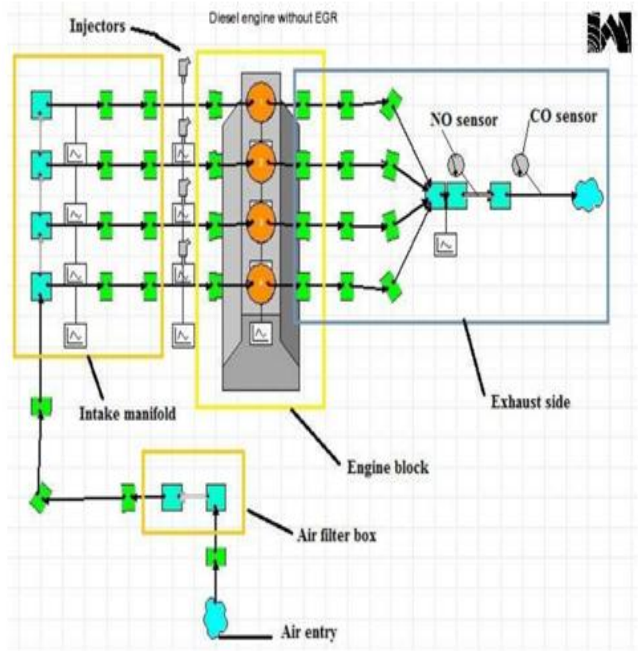


Fig.1 Wave Build Model Of The Diesel Engine (Naturally Aispirated)

b. Construction of the turbocharged diesel engine with EGR 1D wave model.

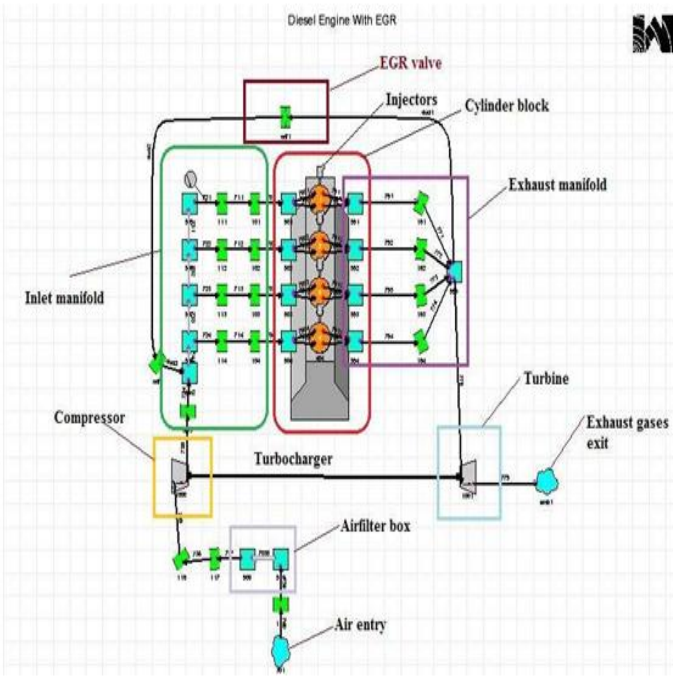


Fig.2 Wave Build Model Of The Diesel Engine (TurboCharged)

## III. RESULTS AND DISCUSSION

In the present study 1D WAVE analysis of the engine system and 3D flow analysis of intake manifold has been carried out. The first section of this chapter covers on the baseline results of 1D and 3D analysis, second section covers on the parametric results of both 1D and 3D analysis and 3rd section covers comparison of the results.

 

A. Baseline results

a.Naturally aspirated engine results

Engine performance characteristics

Engine performance characteristics are constant power output over full speed range. The engine output torque varies hyperbolically with speed and this provides the attractive effort at low speeds. Power of the vehicle increase with an increase in speed up to a point of maximum power. Similarly the torque increases to some speed and then decreases due to decrease in the mean effective pressure. From figure 3 it can be illustrated that the engine designed is a more tuned unit in which the torque is reduced rapidly as the engine speed drops. Power of 50.69 bhp at 5000 rpm and Torque 82.46 N m at 3000 rpm are the values obtained after simulation of the model which are approximately matching with the stock engine value.

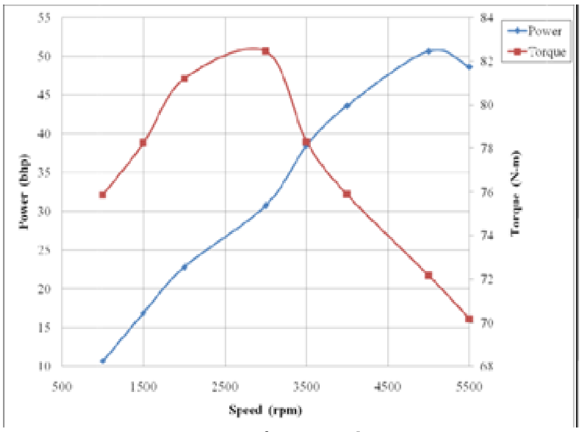


Fig. 3 Engine performance characteristics

Brake specific fuel consumption

Figure 4 illustrates the brake specific fuel consumption plot of the naturally aspirated diesel engine. It is clearly observed that at initial speeds the fuel consumption is less and in between peak torque and peak power speed ranges the fuel consumption is constant and then there is a increase in higher speeds. Therefore the fuel consumption for the selected vehicle is 0.319 kg/kW-hr.

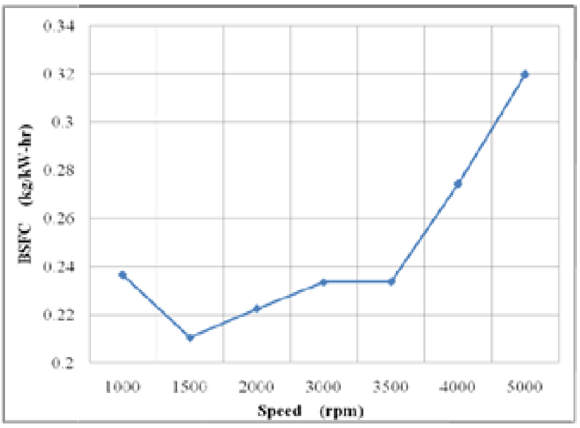


Fig. 4 Brake specific fuel consumption

PV plots

Figure 5 shows the PV plot of the naturally aspirated engine, pressure of 64 bar at 5000 rpm. It is observed that as the speed increases there is an increase in the pressure and reduction in the volume.

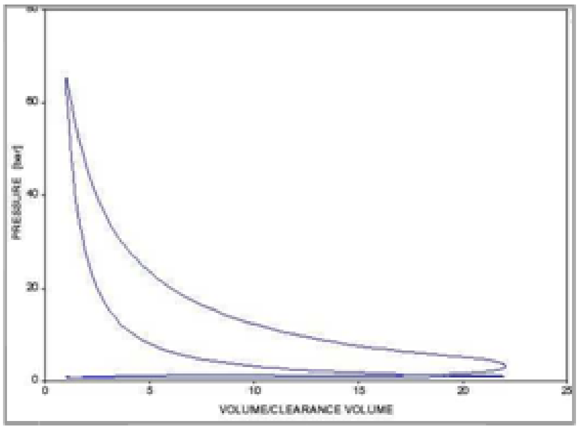


Fig. 5 PV plot @ 5000 rpm

b.Turbocharged diesel engine with EGR Result

Figure 6 shows the engine performance curves of theturbocharged diesel engine. Maximum power of 60.5bhpat 450 rpm and maximum torque of 121.46 N-m at 300 rpmthe result obtained are approximately close to the stock engine values.

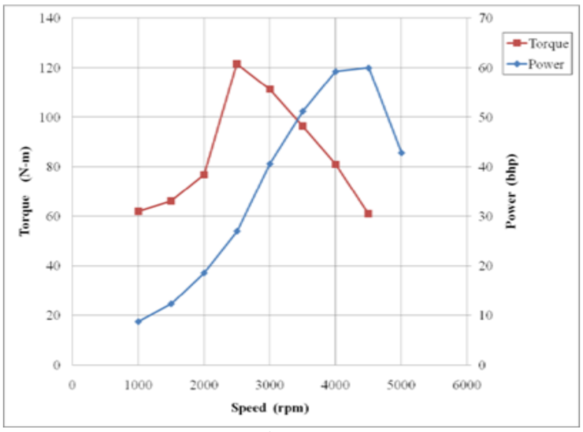


Fig. 6 Engine performancecharacteristics

Brake specific fuel consumption

Figure 7 illustrates the brake specific fuel consumption plot of the turbocharged diesel engine. It is clearly observed that at initial speeds the fuel consumption is less and in between peak torque and peak power speed ranges the fuel consumption is constant and then there is an increase at higher speeds. Therefore fuel consumption for the selected vehicle is 0.284 kg/KW-hr. Fuel consumption is less when compared with naturally aspirated engine because turbocharger and exhaust gas recirculation improves the fuel economy

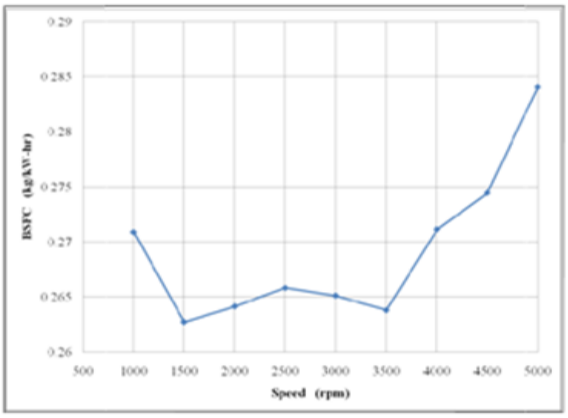


Fig. 7 Brake specific fuel consumption

PV Plot

Figure shows the PV plot of the turbocharged diesel engine, pressure of 135 bar at 5000 rpm. It is observed that as the speed increases there is an increase in the pressure and reduction in the volume. Since it is equipped with turbocharger pressure is high.

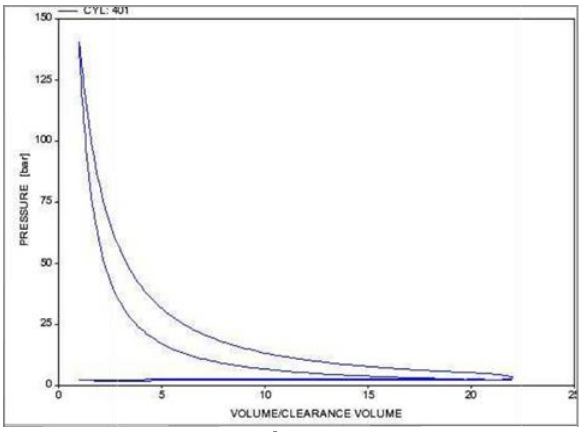


Fig. 8 PV plot @ 5000 rpm

Flowof Nitric Oxide (NO)

To find the mal-distribution of EGR gases in each cylinder flow of Nitric Oxide (NO) is plotted. With 30$^{o}$ inlet valve opening and 230$^{o}$ inlet valve closing a plot of NO against crank angle has been plotted. There is an unequal distribution of EGR gases in the intake manifold. Between range 50$^{o}$ to 100$^{o}$ crank angle there is a sudden increase in the flow of NO.But as the crank angle increases there is decrease in flow of NO.

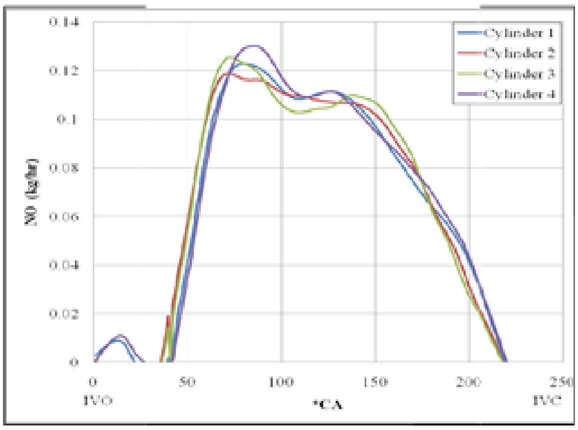


Fig. 9 Flow of NO

NO Concentration

Figure 10 clearly indicates that NO concentration is varying in each cylinder; for cylinder 1 at an initial speed of 1000 rpm it can be clearly observed that there is a decrease in concentration of NO. But as the speed increases beyond 4000 rpm there is a phenomenal increase in the concentration of NO. Hence it can be seen understood that at lower speeds there is high rate of mal-distribution of EGR gases.

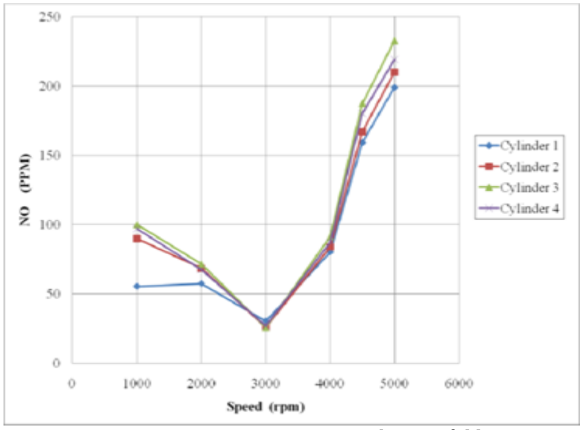


Fig. 10 NO concentration in intake manifold

A similar plot of NO concentration in each runner on the exhaust side of the system has been plotted. It is clearly observed that at initial speedof 1000 rpm in cylinder 1 NO concentration is high because on intake side there is low concentration of NO in cylinder 1. Concentration of NO at 3000 rpm is approximately equal for all the cylinders.

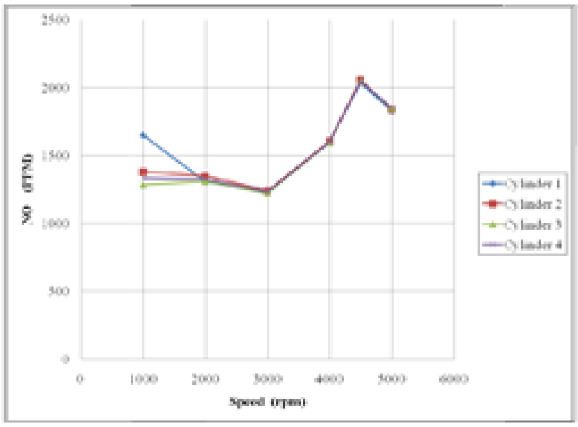


Fig. 11 NO concentration in exhaust manifold

## IV. CONCLUSION

In this study, the influence of EGR position on performance parameters BSFC and NOx emissions were investigated on direct injection turbocharged diesel engine and based on the results following conclusions are drawn. From 1D analysis it has been observed that distribution of re-circulated exhaust gases i.e. NO concentration is not uniform among the cylinders and is influenced by the position of EGR. Similarly flow behavior was analysed in intake manifold by considering EGR mixing to see the distribution of gases

Based on the 1D Wave baseline result parametric studies of eight different cases have been carried out by reviewing literatures and technical papers. From the study it has been found that EGR position plays a vital role to improve engine performance and reduce $NO_x$ emissions.

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