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Influence of EGR (Exhaust Gas Recirculation) on Engine Components Durability & Lubricating Oil Condition

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Abstract*—Diesel engines are extensively used in automotive systems due to their low fuel consumption and very low CO emissions. Despite of these advantages , diesel engines suffer from environmental and health drawbacks such as high levels of NOx and particulate matter. Exhaust Gas Recirculation (EGR) is an effective technique which is being used widely to control the NOx emissions from diesel engines. However, the use of EGR leads to rise in soot emission and it causes the problems inside the engine like degradation of lubricating oil, enhanced engine component wear etc. Therefore, it requires a study of influence of EGR on engine components and lubricating oil. This can be achieved only with different experimental investigation. In the present work , Engine test and Tribology test with lubricants (Without EGR and With EGR) have been carried out to evaluate the effect of EGR on tribo - characteristics of engine components and lubricating oil condition. Influencing parameters like load , speed , temperature were selected as per the engine components operating condition. Friction and wear characteristics were measured and compared with the actual engine wear results to validate the test parameters.

I. INTRODUCTION

In recent years, popularity of diesel engines has increased due to its higher fuel economy and low maintenance cost. At the same time, regulatory emission norms around the world have been tightened in order to control the emissions from vehicles. For diesel engines, these norms particularly focus on emission of oxides of nitrogen (NOx) and particulates. These gases are toxic to human health and environment . For controlling the emissions of NOx from diesel engines, various techniques have been tried e.g. retarded injection timing, injection of diluents in combustion chamber, selective catalytic reduction, exhaust gas recirculation (EGR) etc. Most of these techniques have limitations in practical implementation on the engines. EGR has proved to be an effective method of reducing NOx emissions and is practically implemented in most diesel engines worldwide. In EGR system, part of exhaust gas is recirculated and mixed with air in the intake manifold, replacing an equal amount of fresh air. This reduces the availability of oxygen , increases the heat absorbing capacity of the exhaust gas and air mixture entering the combustion chamber, since specific heat of exhaust gas is significantly higher than air. The reduction in oxygen availability in the combustion zone leads to lower flame temperature. This effectively leads to reduced NOx formation. Though EGR effectively reduces NOx emission, increased number of soot particles leads to increased wear of vital engine parts such as cylinder liner, piston rings, bearings, valve train etc due to abrasive action on the surface and squeezing out of anti-wear film .The wear debris generated by wear of various engine parts contaminates the lubricating oil. Therefore, engines operated with EGR are normally exhibit higher level of lubricating oil contaminations and faster degradation of lubricating oil. This contaminated lubricating oil effects the lubricating principles of engine components and finally leads to wear of engine components. Thickness of boundary layer lubricating oil film is less than diameter of soot particles. At low speed and high load engine operations, typically during start up and shutdown, engine may face insufficient lubrication at boundary layer lubrication zones (i.e. at TDC and BDC positions) of the cylinder liner. Soot particles start acting as abrasives particles, leading to higher wear of surface materials. From a common oil sump, these abrasive particles circulate throughout the engine and continue the chain reaction of wear.

The objective of present work is to compare the performance of a diesel engine using EGR with respect to normal operating engine to evaluate the effect of EGR on engine components for tribological characteristics and it is proposed to use a commercially available Pin-on-Disc wear test rig with normal lubricants and lubricants contaminated with EGR. Influencing parameters like load, speed and temperature were selected as per the engine components operating condition. Friction and wear characteristics were measured and compared with the actual engine wear tests to validate the test parameters .

II. EXPERIMENTAL SETUP AND ENGINE TEST

To study the effect of EGR on physical properties of engine components, engine tests were carried out to compare the performance of engine at normal as well as EGR conditions. New set of components were used for experimentation.

2.1. Engine tests under normal condition (WOEGR)

Engine tests under normal conditions were conducted on 4 stroke engine. Baseline engine used for the experimentation is shown in fig.1. Engine tests were conducted for normal condition where EGR was not used. This test is designed to study the effect of EGR on physical properties of engine components as well as on engine lubricating oil. Following tests were conducted for WOEGR test.

1. Engine components physical properties were measured initially.

2. Engine test for 410 hrs in normal condition (Without EGR)
3. Lubricating oil samples were collected after every 50 hrs interval.
4. Selected components mass and dimensions were measured after 410 hrs.

2.2. Engine test with EGR (WEGR)

For this engine test the base engine was modified with EGR experimental set up. Detail of the experimental set up is given below.

2.2.1 Details of the Experimental setup

Base engine was modified to incorporate an EGR system. The detail of the layout and experimental set up for EGR system is given in Fig 1 and Fig 2.

Fig 1. Engine with EGR System

An EGR experimental set up was used to supply needed exhaust into the intake manifold at different conditions of load and speed. The EGR system consists of exhaust manifold adapter, EGR piping, EGR box, EGR valves, speed sensor, coolant sensor, fuel injection pump with sensor and micro controller. Fig 2 shows the layout of Exhaust gas recirculation system. The detail of the EGR components are given below-

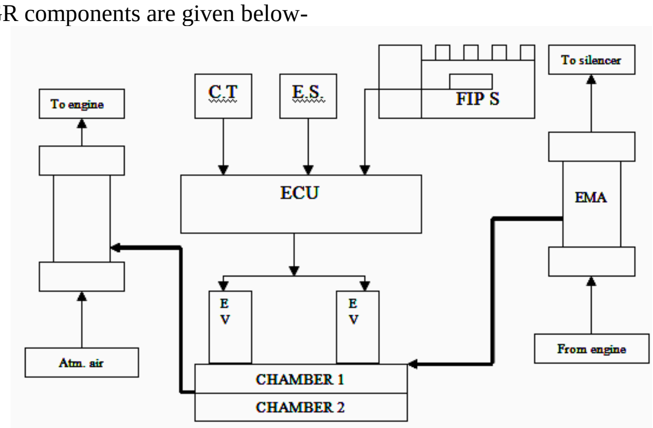

Fig 2. Layout of EGR system

(1) EGR valves

The solenoid operated 12 mm orifice EGR valves was used. The valves are suitable for 2.5 amp current and 12 V. Thus these valves can be operated on Engine batteries.

Specification :

Operating voltage range -11 to 15 volt

Stoke - 3+2 mm

Weight – 1.0 kg (approx)

Operating Temperature - 300 to 1250 for solenoid valve

(2) EGR piping and EGR valve mounting box

The EGR piping was used to provide minimum restriction to the flow of recirculated gas. The EGR valve-mounting box was used considering configuration of inlet and outlet of valves .

(3) Sensors

A. Magnetic pick up (Speed Sensor)

A magnetic pick up is an electromagnetic device. It is mounted on flywheel housing. It senses the engine speed at the flywheel ring gear and generates an AC voltage with its frequency output proportional to the Engine speed. The combination of opening and closing of EGR valves depends on different engine operating speed. The sensor gives the analog signal to the microcontroller and as per the prerequisite program set in the microcontroller the valve actuate. A Two-pin MS connector is provided to connect the magnetic pick up to the engine harness. The magnetic pick up is connected through the harness.

B. Coolant temperature Sensor

A coolant temperature sensor is mounted on the thermostat housing. The sensor was fitted in an adapter. A Two-pin connector was provided to connect the coolant temperature sensor to the harness. As the temperature of the coolant reached 750C the sensor starts giving the output. The output is in the form of on or off. Below 750C there is no output and above 750C there is continuous output. The 750C of coolant temperature indicates the stable working condition of the engine. To inhibit the EGR below 750C coolant temperature the sensor was used to give as an input to microcontroller.

(4) Electronic Control Unit

The ECU senses the various signals like temperature, speed and load on engine and gives signals to the EGR valves. The output signals to the EGR valves depend upon the predetermined database or program generated in the ECU .The various sensors are mentioned below.

The magnetic pickup senses the engine speed at the flywheel ring and generates an AC voltage with its frequency proportional to the engine speed. The signal is sensed by the sensors which is used as an input for ECU.

The EGR valves mounted on EGR box to control the flow of recirculated exhaust gas to engine. The EGR valve opening depends upon the current through the solenoid coils. The ECU compares the electrical signals from the magnetic pick up with a preset reference point (i.e. for different operating conditions). Depending upon engine speed, water temperature and load signal the controller changes the sequence of valve opening

2.2.2 Engine tests conducted with EGR

Similar type of test was conducted in WEGR test , here only the some part of EGR was recirculated back to the cylinder using the EGR valves . Following tests were conducted using EGR

1. Engine components mass were measured initially.
2. 410 hrs Engine testing for different amount of EGR at ambient condition
3. Bosch smoke measurement for different amount of EGR
4. Lubricating oil samples were collected after every 50 hrs
5. interval.
6. Selected components mass and dimensions were measured after 410 hrs.

III. WEAR TEST ON PIN ON DISC TEST RIG

To study the effect of EGR on tribological behaviour of engine components wear tests were performed using the Universal Pin on disk wear test machine based on ASTM G99-90. The specimens were prepared from the materials of the engine components. During testing pin specimen was kept stationary and while the circular disc was rotated. The wear tests were carried out for the period of appropriate time in a lubricating condition. The wear specimens were tested under normal lubricating condition (Without EGR) at room temperature using a pin on disc sliding type wear test machine. Similar experiments were carried out with lubricants contaminated with EGR. The apparatus consists of disc of 205 mm diameter which was used as counterface. The test sample was clamped in a holder and was held against the rotating disc.

The surface roughness of the counterface was maintained constant by polishing the disc. A fresh surface of specimen was used each time and before each test disc and pin specimens were cleaned with acetone to remove any possible traces of grease and other surface contaminants. Every time new track radius was used so that pin was exposed to fresh surface of counter face.

The readings of frictional force were taken directly on the display of load cell. The readings of temperature rise of the specimen were taken by inserting wire in the drilled hole of sample. To study the frictional behaviour of engine components a special chamber was prepared in which 150 oC temperature was maintained. Photograph of pin on disc set up is shown in fig 3.

Fig 3 Pin on Disc Wear Test Rig

Fig 4 Pin on Disc Wear Test Rig with heating chamber

3.1 Procedure for wear testing

1. Specimen pin was mounted on the lever.
2. Initial height of the pin was recorded by dial gauge.
3. Disc radius was measured and pin was kept in contact with the disc.
4. Cantilever flat carrying specimen was made horizontal by use of lever bottle.
5. Necessary load was applied on the pin by adding dead weights proper load was adjusted on the pin.
6. Dial gauge was positioned on the pin and initial reading was taken.
7. Frictional force – load cell indicator was positioned properly.
8. Then speed was adjusted on the motor (below 800 rpm) by using drive control of motor. (Speed 500 rpm approx).
9. Then the test was conducted for required duration and the reading was taken.

IV. RESULTS

4.1 Engine Test Results :

Soot deposits on engine parts were observed after both the engine tests (Fig 5). The soot deposits on various in-cylinder engine parts give a qualitative estimation of amount of soot generation inside the engine and it was observed that the engine operated with EGR has higher soot deposits compared to normally operating engine. The soot generated inside the engine is also passed on the lubricating oil. The soot loading of the lubricating oil was also found higher in case of EGR operated engine compared to engine operating without EGR, which enhances wear of various vital engine parts in the engine. Higher heavy metals content in the lubricating oil drawn from EGR operated engine proves higher wear in engine operated with EGR (Fig 6).

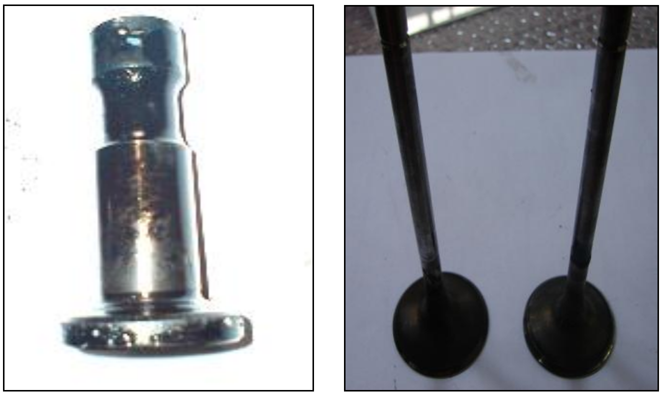

Fig 5 Carbon deposits on valve tappet and Valve

Fig 6 Wear Marks on outer diameter and bottom face of the Valve tappet.

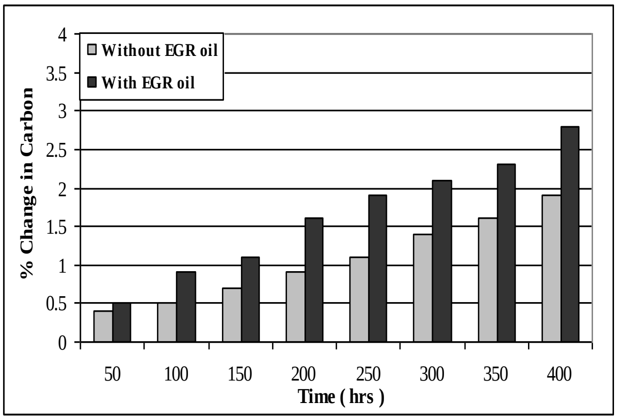

Fig 7 Percent change in carbon content as a function of time of usage of lubricating oil

4.2 Wear Analysis Results :

Friction and wear data from the pin on disc wear tests consists of Coefficient of Friction values and wear values obtained for each of 16 trials on the pin on disc wear test rig. From these data wear under different operating conditions were determined. Graphs were plotted to study the variation of wear and friction for each influencing parameter. For every operating parameter friction curves show increase in Coefficient Of Friction (COF) for the soot contaminated lubricating oil than normal oil. Friction increases with the temperature and it is higher in case of EGR operated engine. Coefficient of Friction increases with percent carbon and decreases with speed. Speed is a most influencing parameter on friction.For every operating parameter wear curves show higher wear for soot contaminated lubricating oil than normal lubricating oil. This demonstrated the detrimental effect of soot on the wear of the parts. The higher wear initially could be due to increased abrasive nature of the soot particles and due to increased scuffing between the materials. Wear increases with increase in load, % C and sliding time.

4.3 Statistical Analysis Results for Wear Test :

Statistical analysis result showed that the speed plays a dominant role on friction and load plays a dominant role on wear of the materials. The effect of percent carbon and speed are significant on friction. Effect of speed is not significant on wear. Effect of percent carbon is more on friction and wear characteristics so it contributes to higher wear of the engine parts than the normal engine. Pin on disc tests also reveals higher wear due to the presence of soot.

V. CONCLUSION

In this work , Effects of exhaust gas recirculation (EGR) on engine components wear and lubricating oil were studied. For this objective Engine test and wear tests were Carried out under normal as well as EGR condition. The following are the major conclusions derived.

1. From the engine tests , it was observed that soot loading of lubricating oil was found higher in case of EGR operated engine as compared to engine operating without EGR, which enhances wear of various vital engine parts in the engine.
2. Higher heavy metals content in the lubricating oil drawn from EGR operated engine proves higher wear in engine operated with EGR.
3. Wear test showed that wear of the engine components is more for EGR lubricating oil than the without EGR oil. Coefficient of friction increased with EGR oil than the normal engine oil. From the wear tests, it was clear that wear from soot contaminated oil (EGR oil) was higher than the wear from less contaminated oil (WOEGR oil). Wear increases with temperature and percent carbon.
4. Coefficient of friction increased with temperature and percent carbon. Coefficient of Friction (COF) decreased with speed and increased with load.
5. Statistical analysis showed that wear increased with higher carbon percent. Speed is a most significant factor for friction and load is the most significant factor for wear of the engine components. The effect of carbon percent is significant factor on friction and wear as compare to other influencing parameters , higher percent carbon increases wear.

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