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# Investigations into the Effect of Exhaust Gas Recirculation (EGR) Adopting Different Air Filters on Performance and Emissions of DI Diesel Engines

P. Ravi chander[1], Dr. B. Sudheer Prem Kumar[2], Dr. K. Vijaya Kumar Reddy[3]
*1) Research Scholar, JNTUH, India.*
*2) Professor, Mechanical Engineering Department, JNT University, Hyderabad, India.*
*3) Professor, Mechanical Engineering Department, JNT University, Hyderabad, India.*

***Abstract:*** *The exhaust gas recirculation technique has proven a better solution to reduce NOx emission in diesel engines. EGR method is taken for the study to investigate the engine behavior on its performance and emissions. The paper the performance characteristics such as brake thermal efficiency(BTE),volumetric efficiency($\eta_{vol}$), exhaust gas temperature(EGT), the exhaust gas emissions such as CO, $CO_2$, NOx, UBHC, $O_2$, and smoke are presented and discussed. The discussion is presented and supported by experimental results. In the experimentation variation in EGR percentage for different air filters is selected for the study. The engine is run by adopting one type of filter at once at different loads for different percentages of EGR such as 5%, 10% and 15%.*

***Key words****: Diesel engine, Air filters, Emissions, EGR.*

## I. Introduction:

Unlike SI engine the CI engine emits smokes and particulate matter along with CO, HC & NOx. Though $CO_2$ is not an emission for local environment, but as a greenhouse gas, it contributes to global warming. These emissions severely affect human health and the lives of animal and plant. The severity of emission effects depend on their concentration and the time of exposure simultaneously. The actual magnitudes of the emissions from SI and CI engines vary due to the difference in their mixture preparation and combustion mechanisms. Air filters play an important role in minimizing exhaust specially particulate matter.

The air filter separation efficiency was studied for particle size of 50 and 100µm, it was found to be 94.4%. The study was made with both experimental and simulation methods. Pressure drop in the analysis was well matched with experimental results [1]. The air filters (SAE J726 & J1669) used in automotive cabin and engine are investigated for their standards and filtration behaviors. The actual air filter performance and their definitions are related to the real time conditions. In the investigation relation between primary function of the air filter and defined one are analyze and the changes for the recommended [2]. The air filter design is critical because of the factors like limited space availability in the induction system for higher velocity of aerosol passing in the primary air filter but this increased velocity causes re-trapping of dust particles and increased dust penetration through the filter [3]. The frequency of replacing the air filter depends on its optimum usage which can reduce its cost and extended its life. The experiments conducted in optimizing geometrical configuration of intake system to keep reduced pressure drop and improved utilization of filter area. CFD analysis was made to improve air flow characteristics through the filters. An eccentricity was suggested in the filter element The eccentricity place a role of maintaining air velocity at constant in annular portion. This constant value of velocity resulted in lowering pressure drop was found to be higher for an eccentricity placed at 15mm distanced from the inlet [4]. When Exhaust Gas in which the Recirculation (EGR) on the performance and emissions of a single cylinder naturally aspirated constant speed diesel engine is studied. The results showed that EGR would be one option to reduce the nitrous oxide emissions, but with a rise in EGR rate the CO, UHC concentrations in the engine exhaust are increased [5 & 6]. When the effects of hot and cold EGR methods on emissions and efficiency of the engine is provided for obtaining different EGR methods in which the performance parameters were studied with and without exhaust gas recirculation of different methods with 10%, 15% and 20% of EGR[7& 8]. The technology adopted for the reticulated foam multilayer filters calls for no servicing and maintenance throughout the life of the vehicle i.e, 150000 miles. The technology adopted for these type of filters facilitates sum unique advantages compare to traditional air filters [9]. The restriction for air flow will be naturally higher in old filter than that of new [10]. When investigation made on air filters and their traps in different locations with different vegetation zones to study the efficiency of air filters used in motor cars. It was revealed that on efficiency filter traps will capture only the airborne particles. The contamination due to vegetation is also consider along with animal derived debris [11]. In this paper the performance characteristics and the exhaust gas emissions of stationary diesel engine are presented and discussed which is supported by experimental results. In the experimentation variation in EGR percentage for different air filters is selected for the study. The engine is run by adopting one type of filter at once at different loads for different percentages of EGR such as 5%, 10% and 15%.

## II. Experimental Setup:

The experimentation is carried out on a single cylinder, four stroke, water cooled, DI engine. The test set up is developed to carry out set experimentation procedures. The layout of the experimental set up is shown in the Fig. 2.1. and Fig. 2.2 shows Photographic View of Computerized Experimental Diesel Engine Setup.

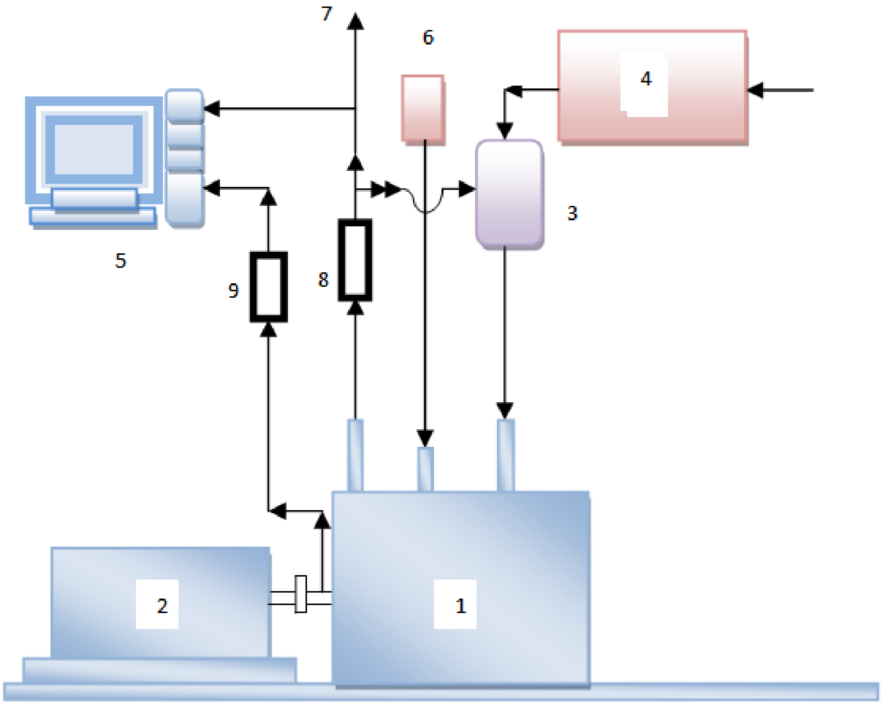



**Fig: 2.1** Layout of Experimental Set up

1) Engine, 2) Dynamometer, 3) Air Filter Housing, 4) Air surge tank, 5) Computerized data acquisition, 6) Diesel fuel tank, 7) Exhaust Manifold, 8) Exhaust gas recirculation unit, 9) Crank angle encoder.


**Fig: 2.2** Photographic View of Computerized Diesel Engine Setup with Air Filter Housing Arrangements and EGR Facility

**Table.1** Engine specification:

| | |
|---|---|
| Make | Kirloskar AV-1 |
| Engine type | 4- stroke single cylinder diesel engine( water cooled) |
| Rated Power | 3.7KW, 1500rpm |
| Bore & stroke | 80mmx110mm |
| Compression rate | 16.5:1 (Variable From 14.3to20) |
| Cylinder Capacity | 553cc |
| Dynamometer | Electrical-AC alternator |

### 2.2 Experimentation Procedure

The experiments are conducted on test engine in different stages. The engine is experimented without air filter considering as baseline operation to make the comparison study. In second stage the engine is run by adopting the air filter of type 1 (AFM1) - Model No. NF 1004 both with new and clogged filters one after the other. In third stage the engine is run by adopting the air filter of type 2 (AFM2) - Model No. NF615 both with new and clogged filters one after the other. In fourth stage the engine is run by adopting the air filter of type 3 (AFM3) - Model No. NF560 both with new and clogged filters one after the other. . In fifth stage the engine is run by adopting the air filter of type 4 (AFM4) - Model No. 0313AC2261N both with new and clogged filters one after the other.

**Fig: 2.4(a)** AFM1 (OLD& NEW)

**Fig: 2.4 (b)** AFM2 (OLD& NEW)

**Fig: 2.4 (c)** AFM3 (OLD& NEW)

**Fig: 2.4 (d)** AFM4 (OLD& NEW)

## III. Results And Discussion

### 3.1 Performance Characteristics

The variation of brake thermal efficiency according to change in brake mean effective pressure of the engine for different filters, AFM1,AFM2, AFM3 and AFM4 with varying percentages of exhaust gas recirculation is presented and discussed below. The exhaust gas percentage is varied like 5, 10 and 15 percentages in the inlet.

### 3.1.1 Brake Thermal Efficiency (BTE)

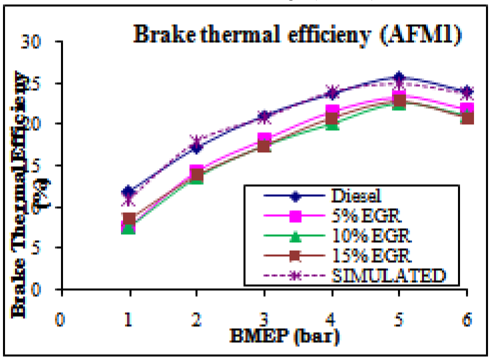



**Fig: 3.1.1 (a)**

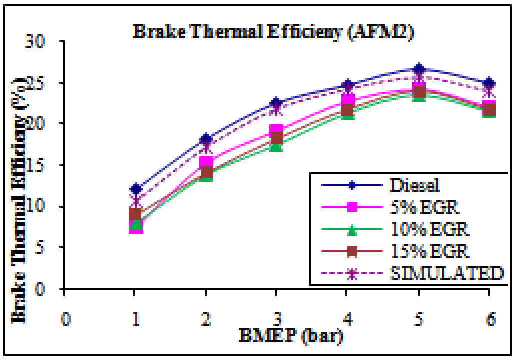



**Fig: 3.1.1 (b)**

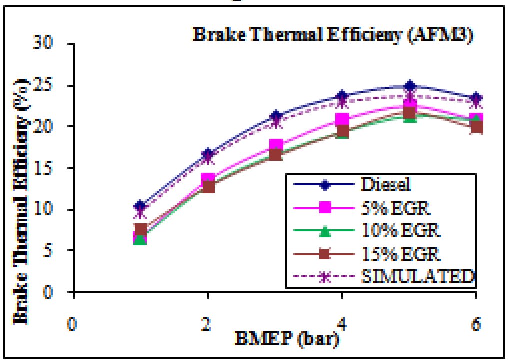



**Fig: 3.1.1 (c)**

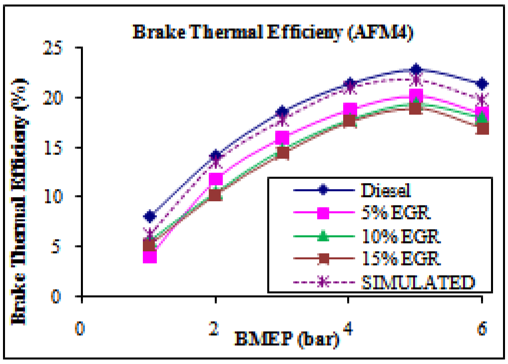



**Fig: 3.1.1 (d)**

**Fig: 3.1.1(a)** to **3.1.1(d)** Effect of EGR percentage on BMEP adopting AFM1, AFM2, AFM3 & AFM4

The figure 3.1.1(a) depicts the effect of percentage of exhaust gas recirculation on brake thermal efficiency for the filter AFM1. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the brake thermal efficiency found to be decreasing when compared to diesel fuel operation without EGR. The variation in brake thermal efficiency is found to be 10, 12 and 15% for 5, 10 and 15% of EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 23.42, 22.56 and 22.91 for 5, 10, and 15% of EGR respectively.

The figure 3.1.1(b) depicts the effect of percentage of exhaust gas recirculation on brake thermal efficiency for the filter AFM2. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the brake thermal efficiency found to be decreasing when compared to diesel fuel operation without EGR. The variation in brake thermal efficiency is found to be 13, 15 and 18% for 5, 10 and 15% of EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 24.23, 23.45 and 23.92 for 5, 10, and 15% of EGR respectively

The figure 3.1.1(c) depicts the effect of percentage of exhaust gas recirculation on brake thermal efficiency for the filter AFM3. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the brake thermal efficiency found to be decreasing when compared to diesel fuel operation without EGR. The variation in brake thermal efficiency is found to be 12, 14 and 16% for 5, 10 and 15% of EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 22.93, 21.24 and 21.67 for 5, 10, and 15% of EGR respectively.

The figure 3.1.1(d) depicts the effect of percentage of exhaust gas recirculation on brake thermal efficiency for the filter AFM4. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the brake thermal efficiency found to be decreasing when compared to diesel fuel operation without EGR. The variation in brake thermal efficiency is found to be 12, 16 and 18% for 5, 10 and 15% of EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 20.14, 19.28 and 18.92 for 5, 10, and 15% of EGR respectively.

### 3.1.2 Volumetric Efficiency

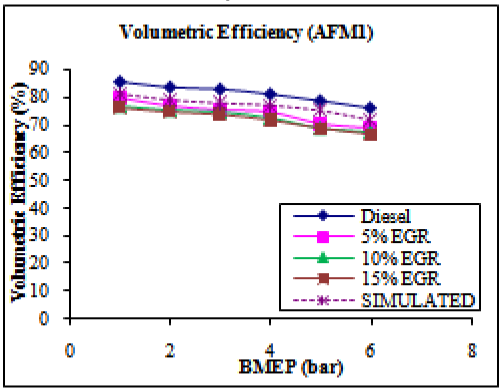



**Fig: 3.1.2 (a)**

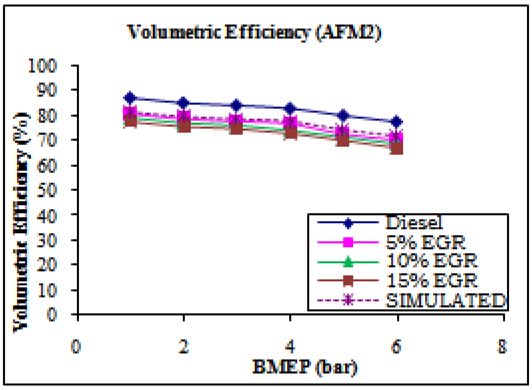



**Fig: 3.1.2 (b)**

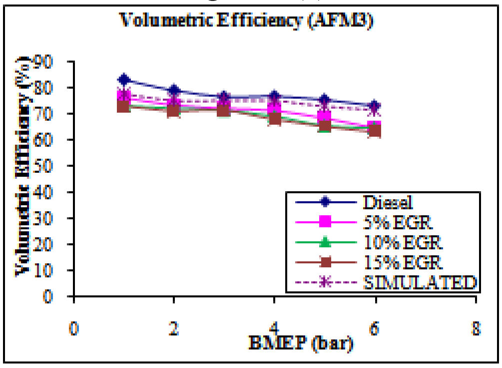



**Fig: 3.1.1 (c)**

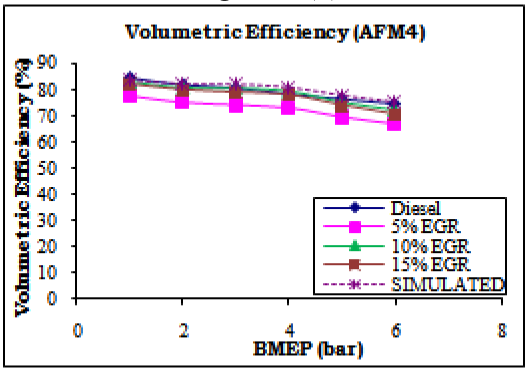



**Fig: 3.1.1 (d)**

**Fig: 3.1.2(a) to 3.1.2(d)** Effect of EGR percentage on volumetric efficiency adopting AFM1, AFM2, AFM3& AFM4

The figure 3.1.2(a) shows the effect of percentage of exhaust gas recirculation on volumetric efficiency for the filter AFM1. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the volumetric efficiency found to be decreasing. But when compared to diesel fuel operation without EGR, the volumetric efficiency is found to be lesser for all percentages of EGR. The decrease in volumetric efficiency is found to be 5% among 5, 10 and 15% of EGR variation. Whereas the percentage reduction in volumetric efficiency is found to be a minimum of 10% when compare to diesel fuel operation without EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 70.5, 69 and 68.5 for 5, 10, and 15% of EGR respectively.

The figure 3.1.2(b) shows the effect of percentage of exhaust gas recirculation on volumetric efficiency for the filter AFM2. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the volumetric efficiency found to be decreasing. But when compared to diesel fuel operation without EGR, the volumetric efficiency is found to be lesser for all percentages of EGR. The decrease in volumetric efficiency is found to be 2% among 5, 10 and 15% of EGR variation. Whereas the percentage reduction in volumetric efficiency is found to be a minimum of 8% when compare to diesel fuel operation without EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 72.9, 71.4 and 70 for 5, 10, and 15% of EGR respectively.

The figure 3.1.2(c) shows the effect of percentage of exhaust gas recirculation on volumetric efficiency for the filter AFM3. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the volumetric efficiency found to be decreasing. But when compared to diesel fuel operation without EGR, the volumetric efficiency is found to be lesser for all percentages of EGR. The decrease in volumetric efficiency is found to be 2.5% among 5, 10 and 15% of EGR variation. Whereas the percentage reduction in volumetric efficiency is found to be a minimum of 12% when compare to diesel fuel operation without EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 68.7, 65.6 and 65.6 for 5, 10, and 15% of EGR respectively.

The figure 3.1.2(d) shows the effect of percentage of exhaust gas recirculation on volumetric efficiency for the filter AFM4. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the volumetric efficiency found to be decreasing. But when compared to diesel fuel operation without EGR, the volumetric efficiency is found to be lesser for all percentages of EGR. The increase in volumetric efficiency is found to be 5% among 5, 10 and 15% of EGR variation. Whereas the percentage reduction in volumetric efficiency is found to be a minimum of 8% when compare to diesel fuel operation without EGR. The simulated values are found to be validated for diesel operation. Brake thermal efficiency at bmep 5bar was found to be 69.7, 75.3 and 74 for 5, 10, and 15% of EGR respectively.

### 3.1.3 Exhaust gas temperature

the variation in exhaust gas temperature due to change in brake mean effective pressure of the engine for different filters, AFM1,AFM2, AFM3 and AFM4 with varying percentages of exhaust gas recirculation is presented and discussed below. The exhaust gas percentage is varied in 5, 10 and 15 percentages in the inlet.

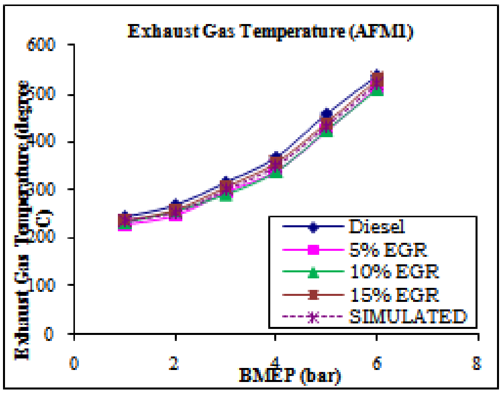



**Fig: 3.1.3 (a)**

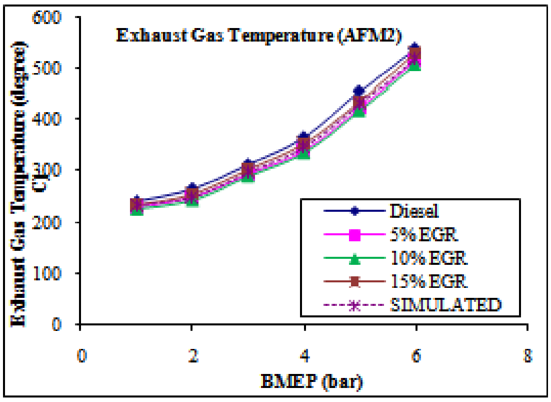



**Fig: 3.1.3 (b)**

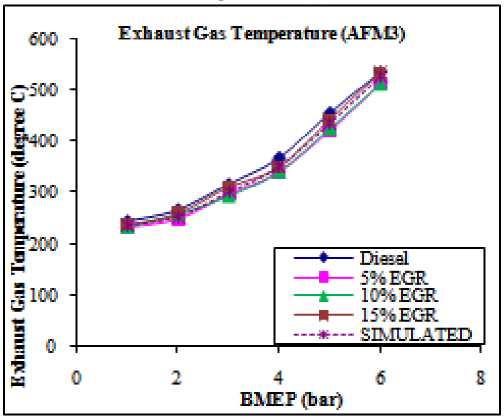



**Fig: 3.1.3 (c)**

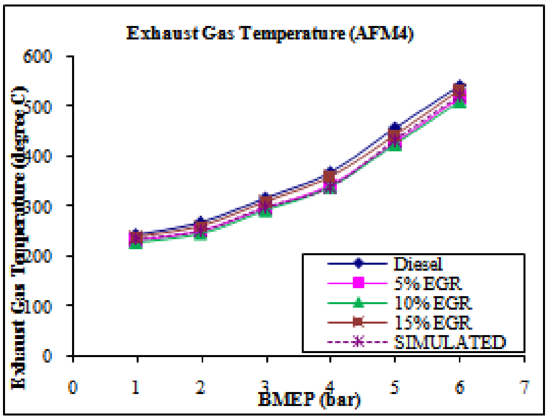



**Fig: 3.1.3 (d)**

**Fig: 3.1.3(a) to Fig: 3.1.3(d)** Effect of EGR percentage on Exhaust gas temperature adopting AFM1, AFM2, AFM3 & AFM4.

In the figure 3.1.3(a) the effect of percentage of exhaust gas recirculation on exhaust gas temperature for the filter AFM1is presented. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the exhaust gas temperature found to be decreasing when compared to diesel fuel operation without EGR for 5 & 10 percent of EGR and later it is found to be increasing at 15% of EGR. The decrease in temperature was recorded in the range of 32, 35$^0$C. The values at BMEP 5 bar for 5 & 10 percent of EGR were 422 and 425$^0$C when compared to 458 of diesel operation without EGR. But the temperature was found increasing in the range of 20$^0$C for 15% of EGR when compared to 5 and 10% of EGR.

In the figure 3.1.3(b) the effect of percentage of exhaust gas recirculation on exhaust gas temperature for the filter AFM2 is presented. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the exhaust gas temperature found to be decreasing in a smaller quantity when compared to diesel fuel operation without EGR for 5 & 10 percent of EGR and later it is found to be increasing at 15% of EGR. The decrease in temperature was recorded in the range of 25, 35$^0$C. The values at BMEP 5 bar for 5 & 10 percent of EGR were 425 and 420$^0$C when compared to

456 of diesel operation without EGR. But the temperature was found increasing in the range of $18^0$C for 15% of EGR when compared to 5 and 10% of EGR.

In the figure 3.1.3(c) the effect of percentage of exhaust gas recirculation on exhaust gas temperature for the filter AFM3 is presented. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the exhaust gas temperature found to be decreasing in a smaller quantity when compared to diesel fuel operation without EGR for 5, 10 & 15% of EGR. The decrease in temperature was recorded in the range of 30, 25 & $15^0$C. The values at BMEP 5 bar were 422, 425 and $445^0$C when compared to 458 of diesel operation without EGR.

In the figure 3.1.3(d) the effect of percentage of exhaust gas recirculation on exhaust gas temperature for the filter AFM4 is presented. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the exhaust gas temperature found to be decreasing when compared to diesel fuel operation without EGR for 5 & 10 percent of EGR and later it is found to be increasing at 15% of EGR. The decrease in temperature was recorded in the range of 30, $35^0$C. The values at BMEP 5 bar for 5 & 10 percent of EGR were 428 and $425^0$C when compared to 459 of diesel operation without EGR. But the temperature was found increasing in the range of $15^0$C for 15% of EGR when compared to 5 and 10% of EGR.

### 3.2 Exhaust Gas Emissions

### 3.2.1 Carbon Monoxide (CO)

Carbon monoxide is the product of the combustion of a hydrocarbon fuel at intermediate stage. Its presence in the exhaust shows the incomplete or improper combustion. It depends mainly on ratio of air fuel mixture.

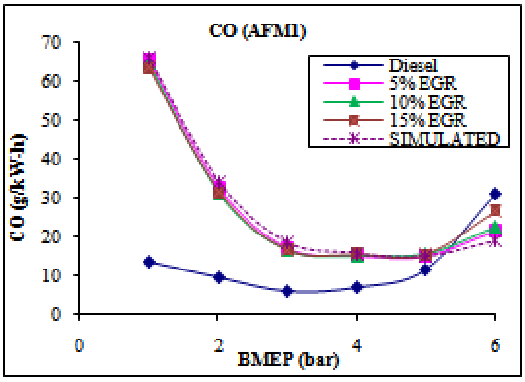



**Fig: 3.2.1 (a)**

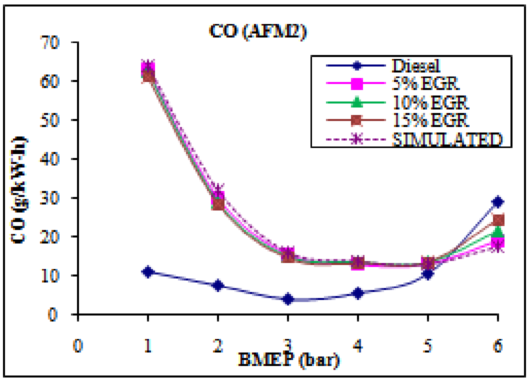



**Fig: 3.2.1 (b)**

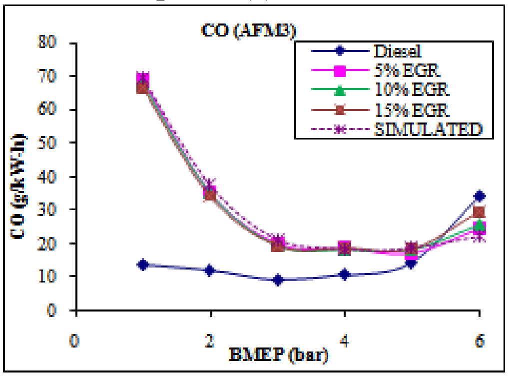



**Fig: 3.2.1 (c)**

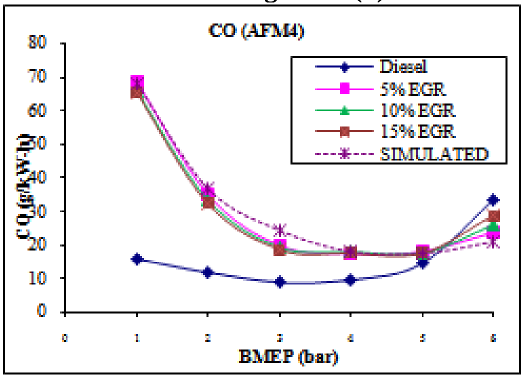



**Fig: 3.2.1 (d)**

**Fig: 3.2.1(a) to Fig: 3.2.1(d)** Effect of EGR percentage on CO adopting AFM1, AFM2, AFM3 & AFM4.

The figure 3.2.1(a) depicts the effect of percentage of exhaust gas recirculation on Carbon monoxide for the filter AFM1. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the Carbon monoxide found at higher values when compared to diesel fuel operation without EGR. For all the percentages of EGR the carbon monoxide levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of CO levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 5 to 10%. But the variation is very large when operated on diesel and are noted 4 to 6 times more than the diesel operation.

The figure 3.2.1(b) depicts the effect of percentage of exhaust gas recirculation on Carbon monoxide for the filter AFM2. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the Carbon monoxide found at higher values when compared to diesel fuel operation without EGR. For all the percentages of EGR the carbon monoxide levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of CO levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 5 to 10%. But the variation is very large when operated on diesel and are noted4 to 5 times more than the diesel operation.

The figure 3.2.1(c) depicts the effect of percentage of exhaust gas recirculation on Carbon monoxide for the filter AFM3. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the Carbon monoxide found at higher values when compared to diesel fuel operation without EGR. For all the percentages of EGR the carbon monoxide levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of CO levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 5 to 10%. But the variation is very large when operated on diesel and are noted 5 to 7 times more than the diesel operation.

The figure 3.2.1(d) depicts the effect of percentage of exhaust gas recirculation on Carbon monoxide for the filter AFM4. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the Carbon monoxide found at higher values when compared to diesel fuel operation without EGR. For all the percentages of EGR the carbon monoxide levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of CO levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 5 to 10%. But the variation is very large when operated on diesel and are noted 4 to 6 times more than the diesel operation.

### 3.2.2 $No_x$

The $NO_x$ percentage in the exhaust is dependent on mean values of cylinder temperature, amount of oxygen availability and residence time of the combustible mixture in the cylinder.

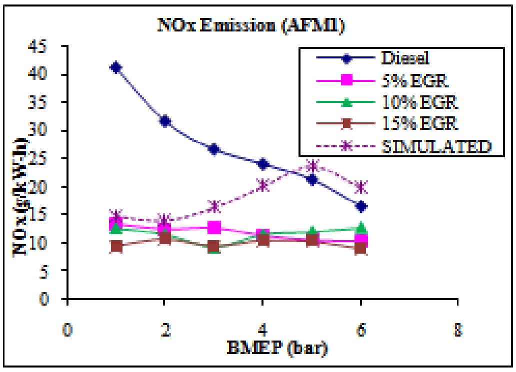



**Fig: 3.2.2 (a)**

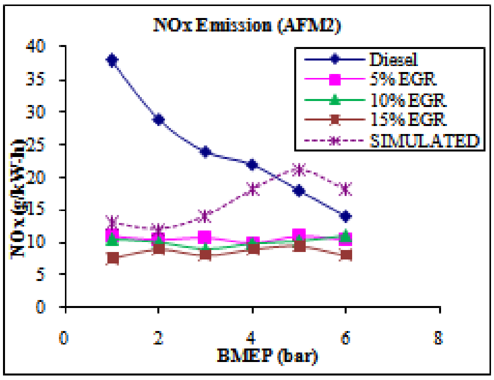



**Fig: 3.2.2 (b)**

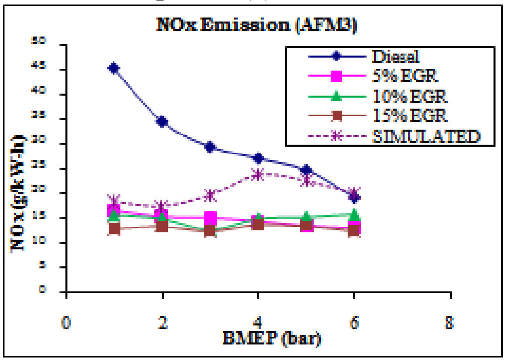



**Fig: 3.2.2 (c)**

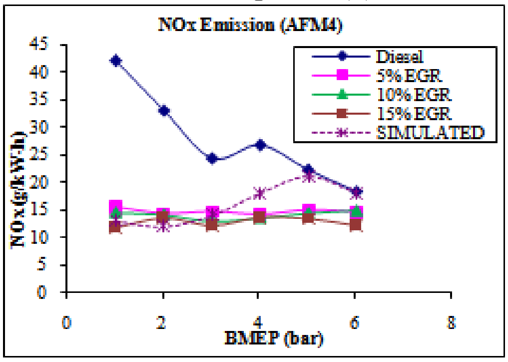



**Fig: 3.2.2 (d)**

**Fig: 3.2.2(a) to Fig: 3.2.2(d)** Effect of EGR percentage on $NO_X$ adopting AFM1, AFM2, AFM3 & AFM4

The figure 3.2.2(a) depicts the effect of percentage of exhaust gas recirculation on $NO_x$ for the filter AFM1. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the $NO_x$ found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the $NO_x$ levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded decreasing as bmep values are increased. The values of $NO_x$ levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 2 to 5%. But the variation is small when operated on diesel and are recorded 2 to 4 times lower than the diesel operation.

The figure 3.2.2(b) depicts the effect of percentage of exhaust gas recirculation on $NO_x$ for the filter AFM2. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the $NO_x$ found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the $NO_x$ levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded decreasing as bmep values are increased. The values of $NO_x$ levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 2 to 4%. But the variation is small when operated on diesel and are recorded 2 to 4 times lower than the diesel operation.

The figure 3.2.2(c) depicts the effect of percentage of exhaust gas recirculation on $NO_x$ for the filter AFM3. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the $NO_x$ found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the $NO_x$ levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded decreasing as bmep values are increased. The values of $NO_x$ levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 2 to 6%. But the variation is small when operated on diesel and are recorded 2 to 4 times lower than the diesel operation

The figure 3.2.2(d) depicts the effect of percentage of exhaust gas recirculation on $NO_x$ for the filter AFM4. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the $NO_x$ found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the $NO_x$ levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded decreasing as bmep values are increased. The values of $NO_x$ levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded in the range of 2 to 5%. But the variation is small when operated on diesel and are recorded 2 to 4 times lower than the diesel operation.

### 3.2.3 Unburn Hydrocarbon (UBHC)

The diesel engine produces higher unburned hydrocarbons when it runs at lower loads and it is a serious problem which is to be addressed. The UBHC level indicates incomplete burning of the fuel may be due to poor fuel distribution, smaller exhaust temperatures leaner air fuel mixture pockets and crevices in the cylinder. The influence of EGR on UBHC emission for different filters AFM1, AFM2, AFM3 and AFM4 is presented in the figures from 5.3.3(a) to 3.3.3(d) and the discussion is followed.

The figure 3.2.3(a) depicts the effect of percentage of exhaust gas recirculation on UBHC for the filter AFM1. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the UBHC found to be higher when compared to diesel fuel operation without EGR. For all the percentages of EGR the UBHC levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of UBHC levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded below 2%. But the variation is very large when operated on diesel and are noted 4 to 6 times more than the diesel operation.

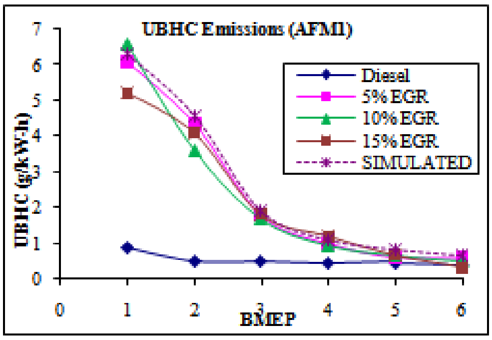



**Fig: 3.2.3 (a)**

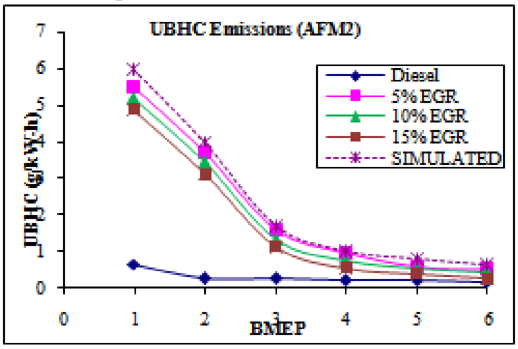



**Fig: 3.2.3 (b)**

The figure 3.2.3(b) depicts the effect of percentage of exhaust gas recirculation on UBHC for the filter AFM2. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the UBHC found to be higher when compared to diesel fuel operation without EGR. For all the percentages of EGR the UBHC levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of UBHC levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded below 3%. But the variation is very large when operated on diesel and are noted 3 to 6 times more than the diesel operation.

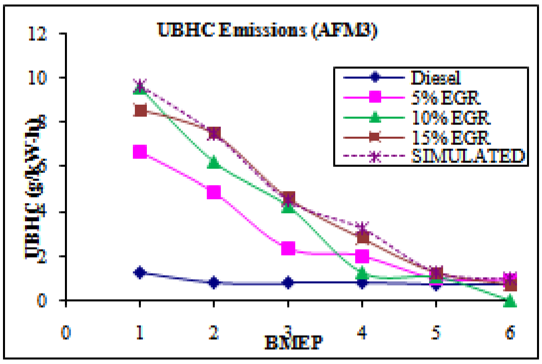



**Fig: 3.2.3 (c)**

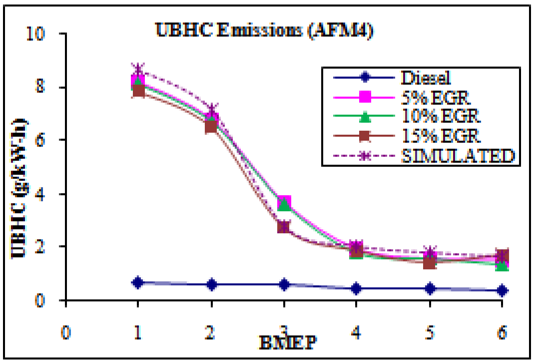



**Fig: 3.2.3 (d)**

**Fig: 3.2.3(a) to Fig: 3.2.3 (d)** Effect of EGR percentage on UBHC adopting AFM1, AFM2,AFM3 & AFM4

The figure 3.2.3(c) depicts the effect of percentage of exhaust gas recirculation on UBHC for the filter AFM4. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the UBHC found to be higher when compared to diesel fuel operation without EGR. For all the percentages of EGR the UBHC levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of UBHC levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded below 3%. But the variation is very large when operated on diesel and are noted 4 to 5 times more than the diesel operation.

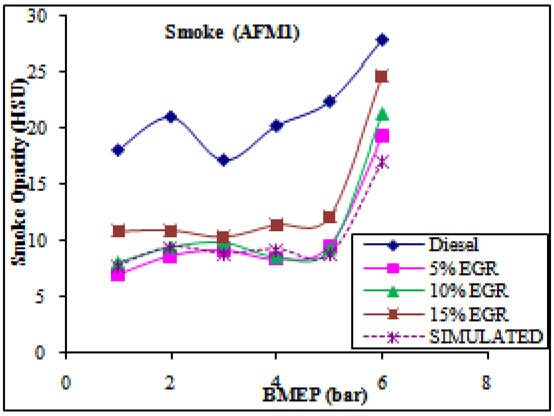
The figure 3.2.3(d) depicts the effect of percentage of exhaust gas recirculation on UBHC for the filter AFM4. For each percentage of EGR the graphs are plotted against bmep the simulated values are also compared. As the percentage of EGR increases the UBHC found to be higher when compared to diesel fuel operation without EGR. For all the percentages of EGR the UBHC levels were found to be higher at all values of bmep. And the values were recorded very high at smaller values of bmep and were recorded decreasing when bmep values are increased. The values of UBHC levels are almost similar as the EGR percentage varied. The variation among them is less significant as they recorded below 2%. But the variation is very large when operated on diesel and are noted 3 to 5 times more than the diesel operation.

### 3.2.4 Smoke

The smoke percentage in the exhaust is the indication of deficiency of oxygen locally in the cylinder of a diesel engine. The variation of smoke as the variation in brake mean effective pressure of the engine for different filters, AFM1,AFM2, AFM3 and AFM4 with varying percentages of exhaust gas recirculation is presented and discussed below. The exhaust gas percentage is varied in 5, 10 and 15 percentages at the inlet.

The figure 3.2.4(a) depicts the effect of percentage of exhaust gas recirculation on smoke for the filter AFM1. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the smoke found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the smoke levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded increasing as bmep values are increased. The values of smoke levels are almost similar among themselves as the EGR percentage is varied. The variation among them is less significant as they recorded in the range of 5 to 10%. But the variation is smaller when operated on diesel and are recorded 2 to 6 times lower than the diesel operation.

The figure 3.2.4(b) depicts the effect of percentage of exhaust gas recirculation on smoke for the filter AFM2. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the smoke found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the smoke levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded increasing as bmep values are increased. The values of smoke levels are almost similar among themselves as the EGR percentage is varied. The variation among them is less significant as they recorded in the range of 5 to 18%. But the variation is smaller when operated on diesel and are recorded 2 to 5 times lower than the diesel operation.



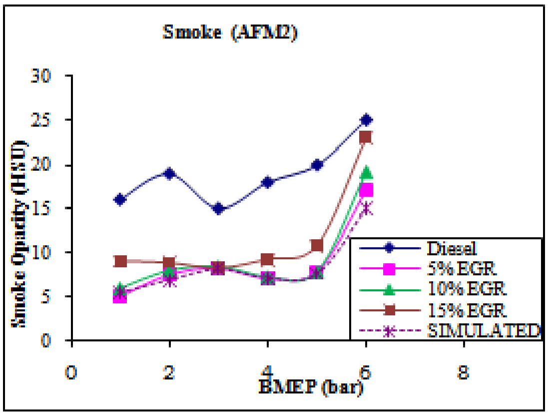
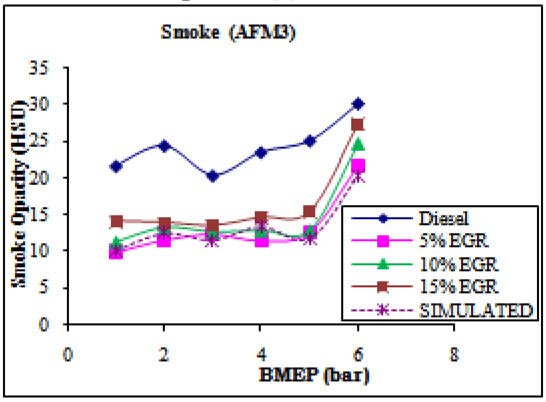




**Fig: 3.2.4 (a)** **Fig: 3.2.4 (b)**



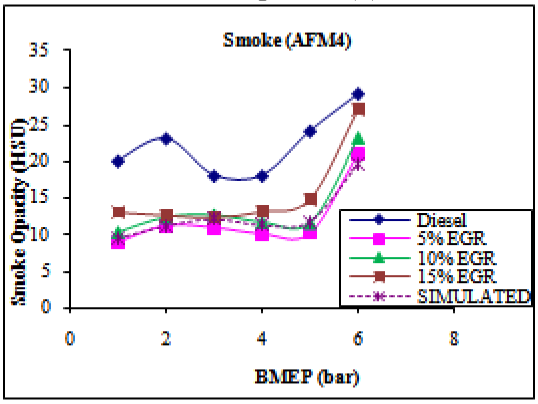




**Fig: 3.2.4 (c)** **Fig: 3.2.4 (d)**

**Fig: 3.2.4(a) to Fig: 3.2.4 (d)** Effect of EGR percentage on smoke adopting AFM1, AFM2, AFM3 & AFM4

The figure 3.2.4(c) depicts the effect of percentage of exhaust gas recirculation on smoke for the filter AFM3. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the smoke found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the smoke levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded increasing as bmep values are increased. The values of smoke levels are almost similar among themselves as the EGR percentage is varied. The variation among them is less significant as they recorded in the range of 4 to 9%. But the variation is smaller when operated on diesel and are recorded 2 to 6 times lower than the diesel operation.

The figure 3.2.4(d) depicts the effect of percentage of exhaust gas recirculation on smoke for the filter AFM4. For each percentage of EGR the graphs are plotted against BMEP the simulated values are also compared. As the percentage of EGR increases the smoke found to be decreasing when compared to diesel fuel operation without EGR. For all the percentages of EGR the smoke levels were found to be lower at all values of bmep. And the values were recorded lower at smaller values of bmep and were recorded increasing as bmep values are increased. The values of smoke levels are almost similar among themselves as the EGR percentage is varied. The variation among them is less significant as they recorded in the range of 5 to 9%. But the variation is smaller when operated on diesel and are recorded 2 to 5 times lower than the diesel operation.

## IV. Conclusions

- The volumetric efficiency is found to better for filter AFM2 due to its design and materials which allows more air flow into the engine cylinder having low pressure differential across the engine cylinder and filter. The exhaust gas recirculation has shown effect when compared to without EGR. With EGR the volumetric efficiency is reduced.
- The filter AFM4 has given better results in brake thermal efficiency for a 15% of exhaust gas recirculation due to the design factors of AFM4 filter.

- Though exhaust gas recirculation has been widely applied in SI engines for reduction of NOx formation, but nowadays in diesel engines it has become common practice. In the investigations it was observed that the use of EGR, NOx reductions are accompanied with an increase in smoke, particulate, unburned hydrocarbon emissions and fuel consumption.

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