Experimental Investigation for NOx reduction on a VCR diesel engine by Exhaust Gas Recirculation

Jitendra Kumar Upadhyay,Ashish Nayyar
Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur-302017 (INDIA)
***Email*-yoursashish2@gmail.com**
Received 16.07.2019 received in revised form 04.08.2019, accepted 05.08.2019

Abstract:The combined effect of EGR and butanol can effectively reduce the Nitrogen Oxides (NO_x) emissions by reducing the combustion temperatures because NO_x formation is a temperature dependent phenomenon in diesel engines. The combined effect of EGR and Butanol blend on Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC) and exhaust emissions will be studied. From literature review it is found that a 15% EGR rate results in maximum BTE and minimum BSFC. It is also found that the combined effect of EGR and Butanol reduces the NO_x emissions by 25% with a slight increase in Carbon Monoxide (CO), Hydro Carbon (HC) and smoke opacity.After optimizing the operating parameter with n-butanol, the combustion and emission studies would be done and further attempt would be made to reduce the NO_x emission using some technique viz. EGR. Tests would also be performed to check the long term usability of the selected fuel. The basic goal of this study is to replace the commercially available diesel with butanol blend mixed fuel and compare the performance of diesel engine with the EGR too.

Keywords: Diesel Engine, N-butanol, EGR, NO_x

2. INTRODUCTION

Diesel engines are more robust and fuel efficient than SI engines. NO_x is one of the main emissions from tailpipe of diesel engine. Diesel engines suffer from high emission of PM and NO_x however HC and CO are lower. NO_x has been reported high in most of the cases with oxygenated additives in comparison to diesel fuel. But some studies reported reduction in NO_x with diesel-oxygenated blends[1].

Butanol (C_4H_9OH) is best source of research as an alternative additive fuel for diesel engines due to its higher heating value and cetane number, more miscibility with diesel, and less hydrophilic compared to methanol and ethanol[2].

Butanol:- Butanol is a type of 4-carbon alcohol also known as butyl alcohol is used commonly as a solvent in various products such as lacquers and enamels in industries. To use as a fuel, it can also be blended with diesel or petrol. The chemical formula of butanol is C_4H_9OH. Butanol is type of the fuel alcohols having more than two carbon atoms in its chemical composition and easily soluble in water. Butanol is generally manufactured by using fossil fuels. It can also be prepared from biomass, which is known as bio-butanol[3].

Advantages of Butanol: N-butanol is an alternative fuel for the conventional transportation fuels. The advantages of butanol are as follows:

High energy content: energy density of n-butanol is lower than petrol’s energy density. But, n-butanol's energy content is comparatively higher among other gasoline alternatives.

Vapour Pressure: If compared with ethanol, butanol has a lower vapor pressure, which tends to lower volatility and emission by evaporation.

Less emissions: Emissions are also very less with butanol. Butanol blend with diesel gives less smoke and other emissions[4].

1.1 NO Formation in CI Engines

- In the CI engines, most NO is formed in the burnedgases resulting from near stoichiometric combustion.
- Kinetically formed NO is frozen at higher levelscompared to SI engines as sudden cooling of the burned gases may be caused due to mixing with cooler air or cylinder charge, thereby freezing the NO decomposition reactions[5].

1.2 NO_2 Formation

Nitrogen dioxide emissions from the spark-ignitionengines square measure negligibly little and represent but a pair of of the whole NOx emissions. NO emissions vary from a couple of hundred ppm to many thousands of ppm whereas, the maximum NO2 emissions are around 60 to 70 ppm only compared to 3000- 4000 ppm of NO at full load conditions[5].

2. EXHAUST GAS RECIRCULATION (EGR)

Exhaust gas recirculation has been wide used since Nineteen Seventies to scale back NOx emissions within the SI engines. As the EGR is applied, excess air decreases. With 25% EGR in a turbocharged engine at full load operation, the excess air ratio decreased from around 1.7 to 1.3. Simultaneously with 25% EGR, the NOx reduced by 85%, smoke increased manifold from around 0.5 Bosch smoke units to 3.5 Bosch units and BSFC increased by 8%. Smoke and BSFC increased sharply beyond about 12% EGR rate.[6]

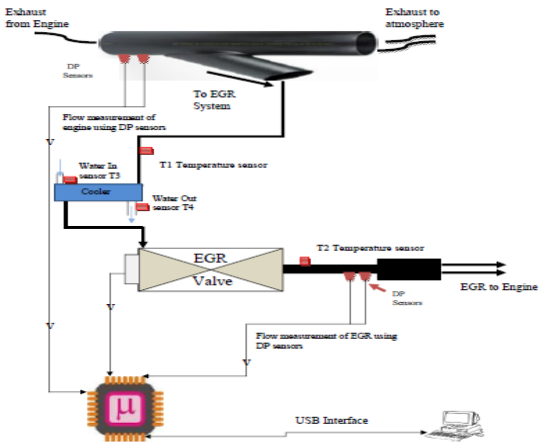

Figure1: Flow Chart of EGR System

N-butanol is a potential alternative to diesel and offers many benefits including a much higher heating value and lower latent heat of vaporization. It also has a higher cetane number than other alcohols and improved miscibility in diesel fuel[7]. Low butanol blends (up to 5vol% butanol content) appear to be a good alternative for compression ignition engine utilization if the difficulties of flash point reduction can be handled in the logistical chain[8]. Butyl alcohol may be a higher various for fuel because of its superior fuel properties and miscibility with fuel than those of fuel and ethanol[9]. Butanol isomer had a few effects on BTE and the NOx and Smoke emissions at middle and high load conditions. It is concluded that 1-butanol is best for gas oil blending in engine[10]. The effects of butanol addition to diesel fuel on emissions were altered with loads. Under low loads, CO emissions increased while NOx emission decreased as butanol blending ratio increased. Under high load conditions NOx emissions increased while CO emissions decreased [11]. EGR, CO and HC emissions square measure low and not laid low with fuel properties; within the Low Temperature Combustion region with higher EGR, n-butanol additive improves the oxidization of CO and HC emissions slightly, whereas still has little impact on NO_X emissions [12].

3. WORKING METHODOLOGY

The methodology of the proposed Investigation is:

- To investigate the performance, combustion and emissions generated by a stationary, VCR, single cylinder CI engine operated on blends of n-butanol as additive in diesel.
- To find out suitable percentage of additives to minimize emissions without altering the performance of CI engine.
- To find out the maximum percentage of exhaust used as intake of engine with additional equipment EGR to reduce NO_X emission as low as possible.

4. EXPERIMENTAL PLAN

The following experimental plan is being followed tocarry out the proposed investigation:

1. Detailed literature review regarding alternative fuel operated CI engines. Study of possible additives in diesel engines and their effects on engine performance and emissions. Finding out the research gap and identifying the additives for proposed work.
2. Study of VCR Engine test rig, Gas analyzer, Smoke meter and EGR system.
3. Generation baseline data using diesel fuel and comparison of results with the literature available for verification.
4. Engine test run with different percentage of n-butanol in diesel to find out optimum blend for minimum NO_X emission and unaltered performance. Analysis of performance and other emissions will also be done.
5. Use EGR system to reduce NO_X emission and increase engine performance with the help of exhaust gas of the engine.
6. Optimize the engine operating parameters for better engine performance with minimum NO_X emission.
7. To prepare the documentation of the research work.

4.1 Experimental Set-up

The engine coupled through suitable coupling to eddy current dynamometer. The engine and dynamometer mounted on rigid steel C-channel frame. It is provided with air tank with orifice mater, exhaust gas calorimeter with digital temperature indicators, necessary sensors for cylinder pressure and crank angle measurement, with necessary software for acquiring the data with appropriate display panel.

4.2 Test Engine Selection and Development of Experimental Setup

A single cylinder, direct injection, four-stroke, vertical, water-cooled, naturally aspirated variable compression ratio multi-fuel engine, with a bore of 80 mm and a stroke of 110 mm was selected for the research study. This check engine, that could be a compact engine; having rated power output of three to five horsepower, factory-made by Technical Teaching instrumentation, city (India). The engine has a provision of loading by eddy current dynamometer. The engine can be started by hand cranking/self-start and it is provided with a centrifugal speed governor. The compression ratio of the engine can be varied by rising and lowering the bore and the head of the engine with the help of handle mounted at the head of the engine. As the bore and the head of the engine are raised and lowered, the clearance volume is changed resulting in the change in the compression ratio. The cylinder of the engine is made of cast iron, it is fitted with a hardened high-phosphorous cast iron liner and the piston is made up of cast aluminium. The water jacket is provided between the cylinder and the cylinder liner. Liberal cooling areas are provided in both cylinder head and barrel. Water circulation is by a centrifugal pump in a closed circuit, which includes heat exchanger and orifice type flow meter. The high rate of circulation of cooling water ensures a uniform temperature in the head.

Figure 2 : Experimental setup connected with EGR system

4.3 Exhaust Gas Recirculation System

The EGR system is designed to reduce the amount of oxides of nitrogen (NO_X) created by the engine during operation periods that usually results in high combustion temperatures, NO_X if formed in high concentrations whenever combustion temperature exceed about 2500°F.

The EGR system reduces NOX production by recirculation small amount of exhaust gases into the intake manifold where it mixes with the incoming air. By diluting the air mixture underneath these conditions, peak combustion temperature and pressure square measure reduced, leading to an overall reduction of NOX output.

The EGR System Consists of the below mentioned items/components:-

1. EGR Control Valve
2. Exhaust Control Valve
3. EGR Cooler (Water cooled type)
4. Exhaust Cooler (Water cooled type)
5. Digital Manometer

4.4 Procedure for taking Observations

1. Start the engine and run for 5 minutes to stabilize the operation. Also remove the battery.
2. Set the EGR and Smoke meter at defined places and calibrate them as per the instructions given in user manual.
3. Set the desired compression ratio and injection pressure using the system provided above the cylinder head.
4. Check the combustion characteristics in simulation software and log data.
5. Now attached Exhaust gas recirculation in exhaust pipe and wait for 2-3 minutes for stable reading.
6. Use Knob of gas analyzer in exhaust pipe and extract reading for emission (NOx).
7. Now change EGR value accordingly and write down readings respectively.
8. After that penetrate smoke meter pipe inside the exhaust. Note down readings after 10-15 seconds.
9. After first reading at no load condition increase the load slowly on engine with the help of the regulator provided at control panel. Load must not be increased suddenly it must be gradual and slow in nature.
10. Now repeat the procedure from point 5 to record observation at particular load condition.
11. After Completion of experiment decrease load gradually up to zero position.
12. Turn off the engine by stopping the fuel supply through lever provided near fuel pump.
13. Close the water supply valves and remove water from calorimeter in order to protect it from rusting.

4.5 Discussion of the experimental performance and emissions results and their interpretation

For baseline data firstly engine was run with diesel only and engine was optimized for compression ratio and injection pressure. In the first set of observation the observations was taken at different compression ratios of 16.5, 17.5 and 18.5 with other parameters remain constant.

With this series of experiments for different compression ratios (16.5, 17.5, 18.5) we select the 18.5 CR having more efficiency with less emissions. Now we fix CR and injection timing and record observations at different injection pressures i.e. 200, 210 and 220 bar.

From experimental data it is clearly indicated that best performance and minimum NOx emission is obtained at 210 bar injection pressure.

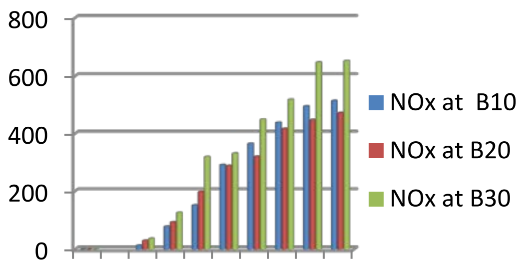

Figure 3 : NO_x emission at different value of butanol blends

4.6 Performance of n-butanol-diesel blends

Performances of n-butanol-diesel blends observed while experiments were done with butanol blends and record all readings for performance and emission parameters.

From the above schematically view it is clear to say that B20 (Diesel 80% with Butanol 20%) is the appropriate value for blending for getting low NOx emission comparatively.

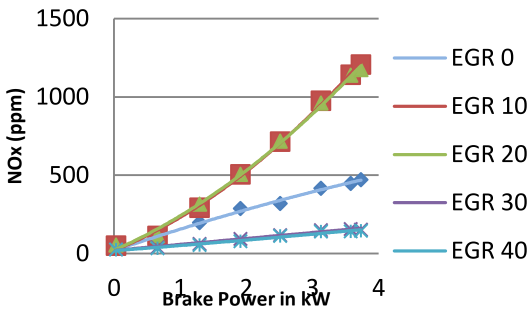

Figure 4 : NO_x emission at different rate of EGR.

4.7 Performance of n-butanol-diesel blends with Exhaust gas Recirculation

Optimum value of butanol blends is B20 and started the EGR experiment with this B20 blend as base fuel and record observations for performance and NOx emission parameters with different value of exhaust gas with the help of EGR system.

Above figure shows curve between Brake Power and NOx with different rates of EGR. From the characteristic it is crystal clear view that for EGR10 and EGR20 NOx value is too high. EGR30 and EGR40 gives us low value of NOx at zero to full load of engine. Low value of EGR is not helping to reduce emission and improving performance of the engine so moderate value of EGR is prime way to reduce NOx emission in engine without affecting performance of the engine.

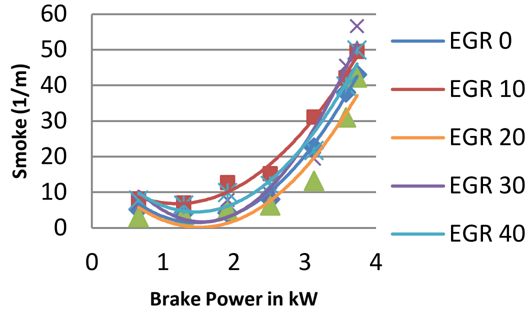

Figure 5: Smoke emission at different rate of EGR

Smoke is also affecting the emission value so for low EGR value it induces high volume of smoke. It's better to choose medium rate of EGR (EGR 30) to avoid high volume of Smoke emission. EGR 20 was giving low smoke as shown above and by increasing the rate of EGR smoke is also increase so EGR 30 is optimum value to reduce NOx emission in high volume without increasing smoke and without altering engine performance.

5. CONCLUSION

1. Computerized Variable Compression Ratio (VCR) Engine provides facility to change engine parameters to optimize the power output and the emissions.
2. The engine showed better performance at 18.5 Compression Ratio and 210 bar Injection pressure for diesel.
3. At Compression Ratio of 18.5, combustion characteristics were improved and tendency of NOx emission decreased. Higher Compression Ratio along with higher Injection Pressure resulted in high NOx and need to be control. To Control NOx emissions without affecting engine performance Butanol was added in diesel.
4. B30 has higher NOx emissions as compare to B20, due to its wider combustion high-temperature region, and lower emissions due to local lower equivalence ratio distribution.
5. Beyond 20% butanol the results were not satisfactory as high amount of additives change the fuel properties and performance starts to deteriorate.
6. After series of experiments it was found that

with 20% butanol blending in diesel and 30% EGR, NOx emissions reduced effectively in comparison to engine operating at diesel only without EGR.

REFERENCES

[1] D. Bharti, A. Agrawal, A. N. Shrivastava, and B. Koshti, “Experimental investigation and performance parameter on the effect of n-butanol diesel blends on an single cylinder four stroke diesel engine,” Int. J. Sci. Res. Publ., vol. 2, no. 8, pp. 1–8, 2012.

[2] M. Zoldy, A. Hollo, and A. Thernesz, “Butanol as a Diesel Extender Option for Internal Combustion Engines,” SAE Tech. Pap. Ser., vol. 1, p. 2014, 2010.

[3] S. Kumar, J. H. Cho, J. Park, and I. Moon, “Advances in diesel-alcohol blends and their effects on the performance and emissions of diesel engines,” Renew. Sustain. Energy Rev., vol. 22, pp. 46–72, 2013.

[4] S. S. Merola, C. Tornatore, S. E. Iannuzzi, L. Marchitto, and G. Valentino, “Combustion process investigation in a high speed diesel engine fuelled with n-butanol diesel blend by conventional methods and optical diagnostics,” Renew. Energy, vol. 64, pp. 225–237, 2014.

[5] L. Siwale et al., “Combustion and emission characteristics of n-butanol/diesel fuel blend in a turbo-charged compression ignition engine,” Fuel, vol. 107, pp. 409–418, 2013.

[6] M. Zhu, Y. Ma, and D. Zhang, “Effect of a omogeneous combustion catalyst on the combustion characteristics and fuel efficiency in a diesel engine,” Appl. Energy, vol. 91, no. 1, pp. 166–172, 2012.

[7] A. Atmanli, E. Ileri, and B. Yüksel, “Experimental investigation of engine performance and exhaust emissions of a diesel engine fueled with diesel-n-butanol-vegetable oil blends,” Energy Convers. Manag., vol. 81, pp. 312–321, 2014.

[8] Z. Şahin and O. N. Aksu, “Experimental investigation of the effects of using low ratio n-butanol/diesel fuel blends on engine performance and exhaust emissions in a turbocharged DI diesel engine,” Renew. Energy, vol. 77, pp. 279–290, 2015.

[9] S. Yamamoto, Y. Agui, N. Kawaharada, H. Ueki, D. Sakaguchi, and M. Ishida, “Comparison of Diesel Combustion between Ethanol and Butanol Blended with Gas Oil,” SAE Tech. Pap. Ser., vol. 1, 2012.

[10] Z. H. Zhang and R. Balasubramanian, “Influence of butanol addition to diesel-biodiesel blend on engine performance and particulate emissions of a stationary diesel engine,” Appl. Energy, vol. 119, pp. 530–536, 2014.

[11] Z. Chen, Z. Wu, J. Liu, and C. Lee, “Combustion and emissions characteristics of high n-butanol/diesel ratio blend in a heavy-duty diesel engine and EGR impact,” Energy Convers. Manag., vol. 78, pp. 787–795, 2014.

[12] B. Yang, M. Yao, W. K. Cheng, Z. Zheng, and L. Yue, “Regulated and unregulated emissions from a compression ignition engine under low temperature combustion fuelled with gasoline and n-butanol/gasoline blends,” Fuel, vol. 120, no. X, pp. 163–170, 2014.