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The effect of EGR rates on performance and emissions of a DI diesel engine fuelled with biodiesel blends.

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Abstract: The influences of different diesel/biodiesel mixtures and EGR rates on brake specific fuel consumption (BSFC), exhaust gas temperature and NO, HC, CO emissions, is studied and demonstrated. In this paper, four strokes direct injection water cooled diesel engine was used. The combustion of biodiesel as an absolute fuel or mixed with diesel in an unchanged engine consequences in advanced combustion, decreased ignition delay and improved heat release rate in the initial uncontrolled premixed combustion phase that caused, higher cylinder peak pressure and temperature that result increased NO. Exhaust gas recirculation (EGR) is an impressive technique for decreasing NO emissions when utilizing biodiesel-diesel fuel mixtures. Reductions in NO and exhaust gas temperature were observed but emissions of HC and CO were found to have increased with usage of EGR. The engine performance and efficiency obtained in biodiesel case were less, which could be attributed to lower calorific value of biodiesel. The increased of BSFC obtained with biodiesel are lower than that of diesel fuel when applying same EGR rate. Thus, EGR has a lower negative influence on engine performance in case of biodiesel compared to diesel fuel.

Key words: biodiesel, diesel engine, emissions, EGR.

Introduction

Today, air pollutants sent out from diesel vehicles, such as nitrogen oxide (NO_x) and unburned hydro carbon (UHC), have created serious air pollution problems in major cities around the world. Compression ignition engine is favored prime movers due to superior driveability and higher thermal efficiency. In spite of their benefits they produce higher levels of NO_x and smoke emissions which will more injurious to human health. Therefore severe emission norms have been required. So that encounter the emission standards and also the fast reduction of petroleum oil reserves conduct of the research for alternative fuels for diesel engines. Biodiesel from vegetable oils are alternative to diesel fuel for diesel engines. The use of biodiesel in diesel engines does not to demand any engine modification. It is achieved from triglycerides through the transesterification process [18]. Physical and chemical processes within a diesel engine such as injection timing, fuel vaporization, and ignition delay are changed with the use of biodiesel fuel relative to petroleum diesel fuel. Lower heating value, lower volatility, higher viscosity and high production cost are some of biodiesel's negative attributes [19]. Biodiesel produces significantly lower emissions of PM, carbon monoxide (CO) and hydrocarbon (HC) [1, 17]. Many scientists have established that with biodiesel fuelled engine produces higher NO_x emissions compared to diesel [8]. To obtain decreases in NO_x emissions, exhaust gas recirculation (EGR) can be utilized with biodiesel in the diesel engines. EGR is an impressive technique of decreasing NO_x emissions from the diesel engine exhaust [1]. Regulating the NO_x emissions mainly needs decreasing of in-cylinder temperatures [2]. However, the application of EGR expansions HC, CO, and PM emissions along with slightly higher specific fuel consumption [8]. An examination was managed on a single cylinder DI diesel engine and calculated the performance and emission characteristics with rice bran methyl ester (RBME) and its blends as fuel with EGR systems [2]. This examination researcher informed that 20% biodiesel blend with 15% EGR produce the less NO_x, CO and HC emissions and also enhanced thermal efficiency and decreased BSFC. Performance of a single cylinder DI diesel engine was investigated with Jatropha oil methyl ester biodiesel (JBD) with hot EGR [4]. Researcher in this investigation optimized 15% EGR gave the sufficient reduction of NO_x emission with minimum probability smoke, CO, UBHC emissions. In this study, the integrated effects of waste cooking oil (WCO) biodiesel combustion with the exhaust gas recirculation (EGR) in order to decrease of NOx emissions, on the engine performance and emissions of a tractor diesel engine are examined and compared with the results achieved from the engine operating on petroleum-based diesel fuel.

1.1. NO_x formation mechanism

NO creation inside combustion chamber can be defined by extended Zeldovich Mechanism [13, 21, 22]. The main reactions near stoichiometric fuel–air mixture governing NO formation from molecular nitrogen are:

$$O + N_2 = NO + N$$

$$N + O_2 = NO + O \qquad (1)$$

$$N + OH = NO + H$$

1.2. Exhaust Gas Recirculation

Cylinder charge weakening with exhaust gas can be systematically arranged into internal EGR and external EGR. With external EGR, exhaust gas is taken from the exhaust port and sent into the inlet port. External EGR has become widely utilized on today's automobile engines. External EGR has a comparatively low cost. It only requires EGR control valve, which can control EGR rate impressively under all work conditions of engine [3]. Only external EGR is debated in this paper. As a result of air displacement with EGR, lower amount of oxygen in the intake mixture is available for combustion. Decrease oxygen available for combustion lowers the effective air–fuel ratio. This impressive decrease in the air–fuel ratio influences exhaust emissions considerably. In addition, the blending of exhaust gases with intake air raises the specific heat of intake mixture, which causes in the reduction of flame temperature. This combination of lower oxygen quantity in the intake air and decrease flame temperature, decrease rate of NOx shaping reactions [5, 6]. The estimation of recirculation amount was explained by relating the amount of CO2 in intake manifold with that in exhaust pipe, through Eq. (2). $[CO_2]_{Intake\ gas}$ was checked in the intake manifold and $[CO_2]_{Exhaust\ gas}$ was measured in the exhaust gases [7].

$$EGR\ (\%) = \frac{[CO2]_{Intake\ gas}}{[CO2]_{Exhaust\ gas}} \qquad (2)$$

2. Materials and Methods

2.1. Fuel preparation

Biodiesel used in this study were obtained from the Bioenergy Research Center, Department of Agricultural Machinery Engineering of Tarbiat Modarres University. The pure material of

Biodiesel was restaurant waste frying oil which was converted to methyl ester (biodiesel) with the trans-esterification method in accordance with the international standards.

2.2. Fuel properties

Some of the characteristics of fuel were calculated due to their relevance, and possibilities in the chemistry - Physics lab, Department of Chemistry of Bu-Ali Sina University, including density, kinematics viscosity and dynamic viscosity. The fundamental specifications such as density, viscosity, calorific value, cetane index, flash point, pour point were measured experimentally. The fuel density was calculated by weighing a known volume of fuel and the viscosity was calculated using a dynamic viscometer to which the measurement principle involved measuring the time needed for a known volume of fuel to fall from a Viscometer. All characteristics were calculated with standard protocol given in the ASTM standards respectively. The basic properties of the fuels are shown in Table1.

Table1. Properties of diesel fuel and biodiesel.

Fuel analysis	Method	biodiesel	Diesel fuel
Density@15°C (g/cm3)	ASTM D4052	0.880	0.845
Kinematic viscosity 40°C (CST)	ASTM D445	5.48	2.8
Cetane number	ASTM D613	60	57
Lower calorific value (KJ/kg)	-	38730	42570
Flash point (°C)	ASTM D92	176	64
Cloud point (°C)	ASTM D2500	-1	2
Pour point (°C)	ASTM D97	-4	0
Free glycerin (%mass)	ASTM D6584	0.016	0.01

2.3. Experimental setup and measurements

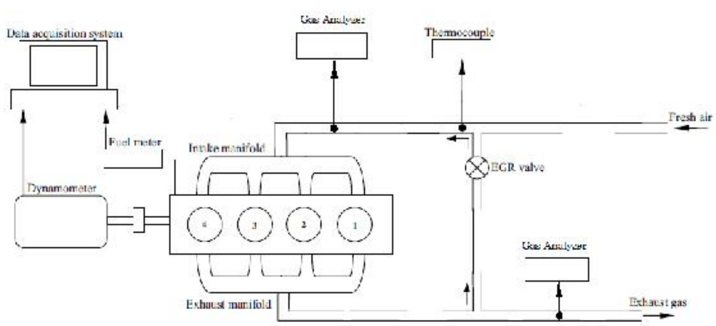

Figure1. Experimental Setup.

Figure1 exhibits a schematic of the diesel engine testing device used for investigating engine performance and emissions. The research were performed on a naturally aspirated, water-cooled, 4-cylinder, direct-injection diesel engine. The characteristics of the engine are shown in Table 2. Exhaust gas temperature was calculated by applying resistance temperature detector (RTD) and K type thermocouples throughout the research. A manual method was used to measure the fuel consumption. In this method, the main tank was replaced with a subsidiary tank and a switching system was used to switch the fuel flow from the tank to the fuel system. To measure power and torque, a dynamometer Model XT-200 made in England was used. The power and torque of the dynamometer were measured automatically by applying a magnetic field.

Table2. Engine specifications

Model	A4-248
Manufacturer	Motor Company makers, of Tabriz, Iran
Number of cylinders	4
Cylinder stroke	127ml
cylinder Diameter	101mm
Maximum power	75 kW/2000 rev/min
Maximum torque	278 Nm/1300 rev/min
Compression ratio	16.0 : 1
Cylinder volume	4.06 it

During all tests, environmental conditions such as temperature and pressure were measured and recorded. Experiments were performed at 5 ° C and pressure of 0.814 atm. An FGA-4100 gas analyzer Made in Taiwan was used to measure emissions. Measurement capabilities, units and precision of this system is presented in Table 3.

Table3. Properties of gas Analyzer.

Measurable	Unit	Limits	Accuracy
Hydrocarbons (HC)	ppm	0-9999	1
Carbon monoxide (CO)	Vol %	0-9.99	0.01
Carbon dioxide (CO2)	Vol %	0-20	0.1
Oxygen (O2)	Vol %	0-25	0.01
Nitrogen monoxide (NO)	ppm	0-5000	1
Oil temperature	(°C)	0-150	0.1
λ	-	0.5-3.0	-

The gas analyser consisted of a sensor that was placed in the exhaust as well as a sensor device placed in the center of the chamber to provide good contact with the smoke. The quantity of EGR can be regulated by a control valve installed in the EGR loop. Also data for HC, NO, CO, CO2, exhaust gas temperature, and fuel consumption were registered. Then, engine performance and emission patterns were analyzed. The optimum EGR rate was found on the basis of performance and emissions of the engine. The percentage of recycled gases are usually described by an EGR ratio, i.e. the mass ratio of recycled gases to the whole engine intake. The fresh air intake includes insignificant amounts of CO2 while the recycled portion carries a substantial amount of CO2 that increases with the EGR flow rate and engine loads. Especially, CO2 is just a combustion product. Thus, it is intuitive and feasible, to measure EGR ratio by comparing the CO2 concentrations between the exhaust and intake of the engine [19, 14].

3. Results and discussion

3.1. Specific Fuel Consumption

The influences of diesel–biodiesel fuel blends on BSFC are showed in Figure 2. The increase of BSFC is due generally to the lower calorific values of biodiesel compared with that of diesel fuel [24]. Therefore, if the engine was fueled with biodiesel-diesel blends, the BSFC will increase due to the produced lower brake power caused by the lower energy content of the biodiesel [31, 32]. At the same time, for the same volume, more biodiesel fuel based on the mass flow was injected into the combustion chamber than diesel fuel due to its higher density [33, 34]. It was found from the experiment that BSFC is increased with increasing in EGR rate because oxygen available for combustion gets reduced for the amount of fuel supplied and density of air decreased thus less oxygen available for combustion. Thus, air fuel ratio is changed and this increases the BSFC [35]. The results obtained are in agreement with that observed by other authors [27].

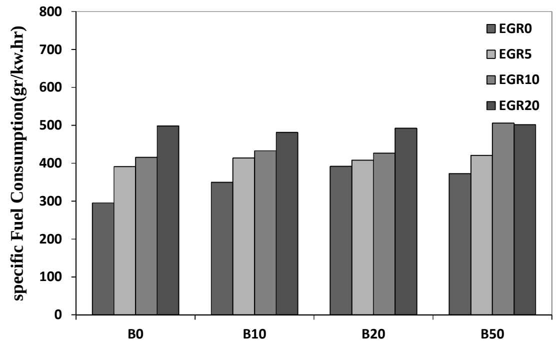

Figure2. Variation of Specific Fuel Consumption for net diesel and diesel-WCO blends with different EGR flow rates.

3.2. Exhaust Gas Temperature

Figure 3 displays the variations of exhaust gas temperature with diesel and blends of biodiesel with different EGR rates.

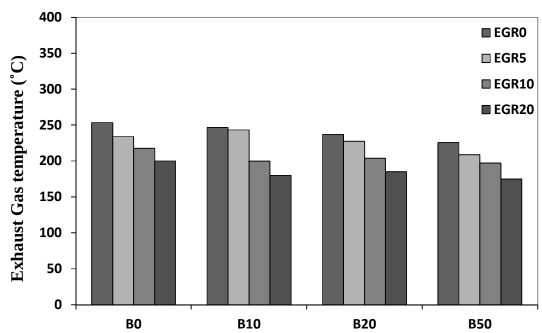

Figure 3. Variation of Exhaust gas Temperature for net diesel and diesel-WCO blends with different EGR flow rates.

In general due to the increase in EGR quantity inside the engine cylinder, there is a reduction in peak combustion temperature and hence a reduction in exhaust gas temperature. The reasons for temperature reduction are relatively lower availability of oxygen for combustion and higher specific heat of intake air mixture as explained earlier [21,22,23]. The results obtained are in agreement with that observed by other authors [24, 25]. However other sources have been obtained showing inconsistencies with the results of the present study [20]. They reported that the addition of EGR increased exhaust gas recirculation. This is caused by shifting the combustion process to a later stage into expansion stroke and also the longer combustion duration for all fuels so that combustion ended later. The temperature of the exhaust gases for B10, B20 and B50 waste cooking oil biodiesel were observed lower than the diesel without EGR. For biodiesel and its mixtures this result is attributed to shorter ignition delays and therefore advanced combustion proportionate to diesel fuel [15].

3.3. Unburnt Hydro Carbon Emissions (UBHC)

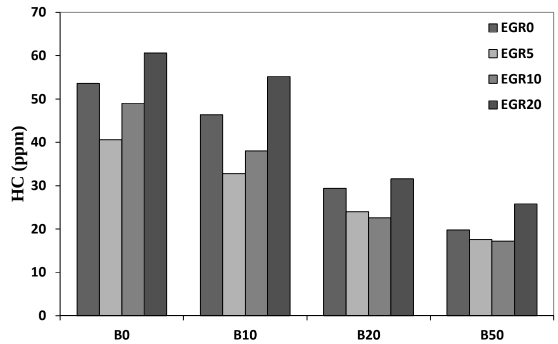

Figure4. Variation of unburned hydrocarbons for net diesel and diesel- biodiesel blends with different EGR flow rates.

The variation of UHC emissions for four fuels with different EGR flow rates is displayed in Figure 4. It is obvious that UHC emissions reduction as the diesel-biodiesel mixtures were used. Several causes have been suggested to describe the reduction in HC emission when replacement customary diesel by biodiesel. The oxygen content in the biodiesel molecule causes to a more complete combustion [16], the higher cetane number of biodiesel decreases the combustion delay, and the combustion timing when utilizing biodiesel is progressed. All of these causes could reduce the HC emissions of the engine. Some researchers found alike consequences of HC emission with diesel-biodiesel blends [26]. On the other hand, raise the EGR flow rate to the lowest level caused by a small reduction in UHC emissions. One cause for this is that a part of the unburned gases in the exhaust of the previous cycle is recirculated and burned in the later cycle. Also, the presence of radicals can aid to initiate the combustion process, particularly with the rise of intake charge temperature due to mixing with exhaust gases. In addition, change in UHC follows a trend with an expansion in EGR ratio resulting in an expansion in UHC emissions. The expansion in UHC emissions is due to the decreasing in oxygen concentration in the inlet charge by the EGR presented into the cylinder which makes the UHC emissions to increase. The results obtained are in agreement with that observed by other authors [21, 27].

3.4. Carbon Monoxide Emissions (CO)

Figure 5 displays the variation of CO emissions of diesel and biodiesel with different EGR rates. From the experiment it was found that emission of CO increased with increasing EGR rate. Higher values of CO were watched for diesel fuel with 20% EGR. Because high EGR flow rates consequences of lack in oxygen concentration in combustion processes and unfinished combustion which cause to rise CO emission. For biodiesel, the extra oxygen content is believed to have partly recompensed for the oxygen lacking operation under EGR. Oxygen compounds of biodiesel have an important role in reducing CO emissions. Oxygen helps complete oxidation of carbon species during the combustion process [28]. Some researchers found alike consequences of CO emission [25].

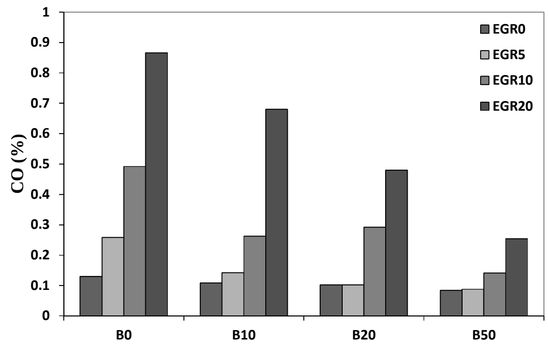

Figure5. Variation of carbon monoxide for net diesel and diesel-WCO blends with different EGR flow rates.

3.5. Nitric oxide (NO)

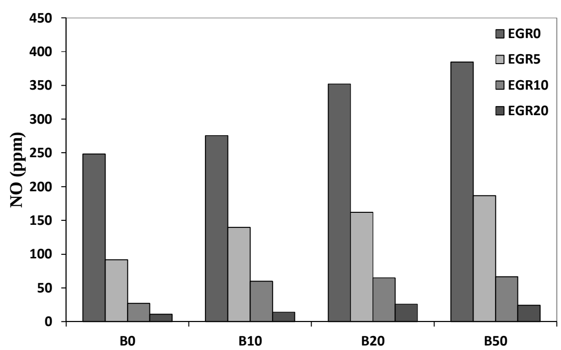

Figure6. Variation of Nitric oxide for net diesel and diesel-WCO blends with different EGR flow rates.

Figure 6 depicts the NO emission, acquired by Diesel, B10, B20 and B50 fuels with different EGR rates. Commonly, biodiesel causes higher NO emissions than diesel fuel. The oxygen content of biodiesel is a significant parameter in the high NO formation levels, because the oxygen content of biodiesel provides high local peak temperatures and a corresponding excess of air [14]. Therefore, the higher NO emissions can be ascribed to the more complete combustion of the biodiesel with the existence of more oxygen in the combustion chamber [12]. On the other hand, the NO emissions incline to reduction meaningfully with a rise in EGR ratio due to the increase in total heat capacity of combustion chamber charge by EGR, which reduces the peak combustion temperatures. This is due to the fact that attendance of inert gases such as CO2 and H2O in the combustion chamber decreases the peak combustion temperature, and also it substitutes the oxygen in the combustion chamber. The results achieved are in agreement with that observed by other authors [29, 30].

4. CONCLUSIONS

EGR is a very useful technique for reducing the NO_x emission. In this article, an experimental study was performed on Tractor engine utilizing diesel fuel, B10, B20 and B50 with exhaust gas recirculation. The influence of blending biodiesel (waste cooking Oil) on emissions and performance were analyzed. EGR displaces oxygen in the intake air by exhaust gas re-circulated to the combustion chamber. Exhaust gases lower the oxygen concentration in combustion chamber and increase the specific heat of the intake air mixture, which results in lower flame temperatures. The consequences of this study may be summarized as follows:

1. When the engine utilizes biodiesel, the power reduces and BSFC increases due to the lower calorific value of biodiesel compared to net diesel fuel. However, increasing EGR flow rates caused in reduces in power and increases in BSFC for both net diesel fuel and WCO blends.
2. It is determined that the NO emissions rise with increasing biodiesel percentage. Applying EGR was an impressive technique to reduce the NO emission. The NO emissions were reduced with a rise in the EGR flow percentage for both net diesel fuel and WCO mixtures.
3. The emissions of CO and UHC were established to be lower with increasing biodiesel percentage. Applying slight amount of EGR caused by a slight reduction in HC emission. However, Increasing EGR flow rates to high levels caused in significant increase in CO and HC emissions for both net diesel fuel and WCO mixtures.

Reference

[1] K. Rajan, K. R. Senthilkumar. Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics of Diesel Engine with Sunflower Oil Methyl Ester. Jordan Journal of Mechanical and Industrial Engineering. Volume 3, Number 4, December 2009. ISSN 1995-6665 . Pages 306 – 311.

[2] D. Agarwal, S. Sinha, A. K. Agarwal, "Experimental investigation of control of NOx emissions in biodiesel – fueled compression ignition engine". Renewable Energy, Vol. 31, 2006, 2356-2369.

[3] Bai Yun-long, Wang⁄Zhi, Wang Jian-xin. Part-load characteristics of direct injection spark ignition engine using exhaust gas trap. Appl Energy 2010;87:2640–6.

[4] Pradeep, R. P. Sharma, "Use of HOT EGR for NOx control in a compression ignition engine fuelled with bio- diesel from Jatropha oil". Renewable Energy, Vol. 32, 2007, 1136-1154.

[5] N. Ladommatos, R. Balian, R. Horrocks, L. Cooper, The effect of exhaust gas recirculation on soot formation in a high-speed direct-injection diesel engine, in: SAE 960841, 1996.

[6] G.H. Abd-Alla, Using exhaust gas recirculation in internal combustion engines: a review, Energy Convers. Manage. 43(2002) 1027–1042.

[7] J.M. Desantes, J. Galindo, C. Guardiola, V. Dolz, Air mass flow estimation in turbocharged diesel engine from in-cylinder pressure measurement, Exp. Therm. Fluid Sci. 34 (2010) 37–47.

[8] Y. Yoshimoto, M. Onodera, H. Tamaki, "Reduction of Nox and smoke and BSFC in a Diesel Engine Fueled by BiodieselEmulsion with Used Frying oil". SAE Transaction,1999-01-3598, 1913-1929.

[9] Zheng, M., Reader, G. T. And Hawley, J. G. 2004. Diesel engine exhaust gas recirculation-a review on advanced and novel concepts. Energy Conversion and Management 45:883-900.

[10] I. Sugozü, C. Öner and S. Altun., "The performance and emissions characteristics of a diesel engine fuelled with biodiesel and diesel fuel", International Journal of Engineering Research & development, Vol.2, No.1, 2010.

[11]. Tsolakis, A., Megaritis, A., Wyszynski, M. L. And Theinnoi, K. 2007 . Engine performance and emissions of a diesel engine operating on diesel- RME (rapeseed methyl ester) blends with EGR (exhaust gas recirculation) Energy 32:2072-2080

[12] G. Labeckas, S. Slavinskas., "The effect of rapeseed oil methyl ester on direct injection diesel engine performance and exhaust emissions", Energy Conversion and Management, 47: pp.1954–67, 2006.

[13] J.B. Heywood, Internal Combustion Engines Fundamentals, International Ed., Mc-Graw Hill, New-York, 1988.

[14] A.N. Özsezen, M. Çanakçı, C. Sayın., "Effects of biodiesel from used frying palm oil on the exhaust emissions of an indirect injection (IDI) diesel engine", Energy & Fuels, 22, pp.2796–2800, 2008.

[15] Hansen, A. C., Gratton, M. R. And Yuan, W. 2005. Steady state diesel engine performance and NOx emissions with selected biofuels. ASAE annual international meeting. Tampa, Florida. 17-20 July 2005, Paper number 056119.

[16] Karavalakis G, Stournas S, Bakeas E. Light vehicle regulated and unregulated emissions from different biodiesel. SCI Total Environ 2009;407:3338e46.

[17] Monyem, A., Van Gerpen, J. H. and Canakci, M. 2001. The effect of timing and oxidation on emissions from biodiesel-fueled engines. Transactions of the ASAE **44**(1):35-42.

[18] Tat, M. E., Van Gerpen, J. H. and Wang, P. S. 2007. Fuel property effects on injection timing, ignation timing, and oxides of nitrogen emissions from biodiesel-fueled engines. Transactions of the ASAE. 50(4):1123-1128.

[19] Jiafeng, S., Jerald, A. C. and Timothy, J. J. 2010. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines. Progress in Energy and Combustion Science **36**:677-695.

[20] Rajan K, Senthilkumar KR. Effect of Exhaust Gas Recirculation (EGR) on the Performance and Emission Characteristics of Diesel Engine with Sunflower Oil Methyl Ester. Jordan Journal of Mechanical and Industrial Engineering 2009;34:306 - 311.

[21] Jaffar Hussain, K. Palaniradja, N. Alagumurthi, R. Manimaran. Effect of Exhaust Gas Recirculation (EGR) on Performance and Emission characteristics of a Three Cylinder Direct Injection Compression Ignition Engine. Alexandria Engineering Journal (2012) 51, 241–247.

[22] Agarwal Deepak, Singh Shrawan Kumar, Agarwal Avinash Kumar. Effect of Exhaust Gas Recirculation (EGR) on performance, emission, deposits and durability of a constant speed compression ignition engine. Appl Energy 2011;88:2900–7.

[23] Roy Pratibhu, Sinha Indranil, Kumar Mandal Bijan, Kumar Chowdhuri Achin. The effect of exhaust gas recirculation (EGR) in CI Engine. International Journal of Emerging Technology and Advanced Engineering Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 106-111.

[24] V.Manieniyan, S.Sivaprakasam. Experimental Analysis of Exhaust Gas Recirculation on DI Diesel Engine Operating with Biodiesel. International Journal of Engineering and Technology Volume 3 No. 2, February, 2013.

[25] Venkateswarlu Kavati, Murthy Bhagavathula, Venkata Subbarao Vissakodeti. The Effect of Exhaust Gas Recirculation and Di-Tertiary Butyl Peroxide on Diesel-Biodiesel Blends for Performance and Emission Studies. International Journal of Advanced Science and Technology Vol. 54, May, 2013.

[26] Ghosh. S, Dutta. D. The Effects of EGR on the Performance and Exhaust Emissions of a Diesel Engine Operated on Diesel Oil and Pongamia Pinata Methyl Ester (PPME).

International Journal of Engineering Inventions. ISSN: 2278-7461, ISBN: 2319-6491. Volume 1, Issue 12 (December 2012) PP: 39-44.
[27] Bharathi Prathibha, G.Prasanthi. Investigation on the Effect of EGR with Karanja Biodiesel and Grooved Piston with Knurling In an Internal Combustion Engine. IOSR Journal of Engineering (IOSRJEN). e-ISSN: 2250-3021, p-ISSN: 2278-8719. Volume 2, Issue 9 (September 2012), PP 25-31.
[28] Kwanchareon P, Luengnaruemitchai A, Jai-In S. Solubility of a diesel–biodiesel–ethanol blend, its fuel properties, and its emission characteristics from diesel engine. Fuel 2007; 86(7-8):1053–61.
[29] Agarwal, D., Singh, S. K., Agarwal, A. K., 2011, “Effect of Exhaust Gas Recirculation (EGR) on performance, emissions, deposits and durability of a constant speed compression ignition engine”, Applied Energy, 88:2900–2907.
[30] Anandavelu, K., Alagumurthi, N., Saravanan, C. G. 2011, “Performance and emission studies on biofuel-powered Kirloskar TV-1 direct-injection diesel engine with exhaust gas recirculation”, International Journal of Sustainable Energy, 30:S66–75.
[31] Aydin H, Bayindir H. Performance and emission analysis of cottonseed oil methyl ester in a diesel engine. Renew Energy 2010; 35:588–92.
[32] Ozsezen A. N, Canakci M, Turkcan A, Sayin C. Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters. Fuel 2009; 88:629–36.
[33] Lin B., Huang J., Huang D. Experimental study of the effects of vegetable oil methyl ester on DI diesel engine performance characteristics and pollutant emissions. Fuel 2009; 88:1779-85.
[34] Song J-T, Zhang C-H. An experimental study on the performance and exhaust emissions of a diesel engine fuelled with soybean oil methyl ester. P I Mech Eng D-J Aut 2008; 222:2487–96.
[35] Dangar Harshraj, Gaurav P. Rathod. Combine Effect of Exhaust Gas Recirculation (EGR) and Varying Inlet Air Pressure on Performance and Emission of Diesel Engine. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 6, Issue 5 (May. - Jun. 2013), PP 26-33.