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Investigating the Performance and Emission Characteristics of a Variable Compression Ratio Diesel Engine Fueled with Waste Plastic Oil

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Abstract:- Rapid depletion, rising prices and hazardous environmental issues related to conventional fossil fuel resources are the major concern today all over the world. And the solution is to go beyond the conventional approach and find an alternative which can replace the existing fossil fuels and meet the requirements upto significant extent. In the same context waste plastic oil can be used as an alternative to conventional fuels as it has dual advantage, first is extraction of valuable energy content in the waste plastic and the second is to give a solution for huge problem of disposing the waste plastic generated by the various household and industrial activities. In this work the performance and emissions of waste plastic oil was compared and analyzed with standard diesel on a four stroke, single cylinder, water cooled TV1 model 3.5 Kw diesel engine. The blend used was 10%-25% waste plastic oil in diesel. The performance and emissions were obtained and then compared with the standard diesel fuel. Various parameters such as Brake Thermal Efficiency, Brake Specific Fuel Consumption, Exhaust Gas Temperature are determined at all operating load conditions and at variable compression ratio 16-18 and emissions such as CO, CO_2, HC and $NO_X$are analyzed.

Keywords- *diesel engine, waste plastic oil, performance and emissions.*

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I. INTRODUCTION

Plastics are light-weight and long hydrocarbon chained organic materials which is comes from petroleum products or crude oil products**(Juniza Md Saad and Paul T. Williams et al, 2016)**.The waste plastic are huge supporting alternative resources for effectively utilizing and depleting the non-renewable fossil fuel resources **(P. Senthil Kumar and Sankarnarayanan et al, 2016)**. The demand of conventional fossil fuel are very high for the developing countries as India. Due to ever increasing demand for plastic, so the huge growth rate of waste plastic production per year in India **(Pouya Mohammadi et al, 2012)**. In 2015-16 the total global plastic almost reached 335 million tonnes worldwide. According to the central pollution control board, almost 5.9 million tonnes of waste plastic is produced yearly in India **(Ioannis Kalargaris et al, 2017)**. Out of this only upto 50%-70% is recycled and other 7000tonnes of waste plastic is going to the landfilling per day. But landfilling is not a right option for disposing waste plastic because of their slow degradation rates. Due to which some pollutants are generated to the air and also the causes of the environmental issues**(S. Murugan and Sai Gu et al, 2015)**.

The waste plastic is a mixture of c_{10}-c_{20} long chained hydrocarbon organic compounds. The waste plastic contains mostly 70% HDPE by weight and other polymer matters **(M. Mani and G. Nagarjan et al, 2009)**.Recycling, reusing, incineration and energy recovery techniques converts the waste plastic materials into alternative fuel. Pyrolysis process is best techniques for the conversion of waste plastic to valuable energy in the form of liquid and gases **(S.L. Wong et al, 2015)**. In pyrolysis process yielded waste plastic 70-75% by weight, solid coke 15-20% by weight and gaseous fractions 5% by weight. For thermal decomposition of waste plastic 350°C -400°C temperature is required **(P. Senthil Kumar and G. Sankaranarayanan et al, 2016)**.

The incremental growth in both population and industries has created a more demand for energy. Due to high consumption and more utilization of conventional fossil fuel resources are getting depleted rapidly **(D. Damodharan et al, 2016)**.However, only a few works have been carried out to evaluate the performance and emission characteristics of waste plastic oil blends with standard diesel in a diesel engine. The aims of this work is the use of waste plastic pyrolysis oil as an alternative fuel for 4-stroke, single cylinder, TV 1 model diesel engine to analyze the performance and emissions for high speed DI engine.

Cost analysis of waste plastic oil

The availability of waste plastic in India are very high due to the more population and more industrial areas. So the total growth production of waste plastic in different cities in India such as Meerut

4.2 MT/day,Gandhinagar5.3 MT/day, Itanagar6.2MT/day, Ranchi 9.42MT/day, Dehradun 14.25MT/day, Chandigarh 9.01MT/day, Bhopal 24.3MT/day, Allahabad 19.2 MT/day, Agra 40.54MT/day, Lucknow70.65MT/day, Chennai 435.3MT/day, Mumbai 425.4MT/day, Kolkata 430.3MT/day, Hyderabad 195.5MT/day, Delhi

688.8MT/day. So total cost of 1 kg waste plastic in rupees and 1lit. Waste plastic oil in rupees shows in below table1.

Table 1 cost for 1 kg of input waste plastic and cost of output of waste plastic oil

Input	Rate per kg(Rs)	Rate per lit.(Rs)
Waste plastic	12	22.50
Labour	5	7.65
Service charges	2.5	1.50
Total	19.5	31.65

Nomenclature

Abbreviation	Meaning
B_0	Blend 0%waste plastic oil and 100% diesel oil
B_{10}	Blend 10%waste plastic oil and 90% diesel oil
B_{15}	Blend 15%waste plastic oil and 85% diesel oil
B_{20}	Blend 20%waste plastic oil and 80% diesel oil
B_{25}	Blend 25%waste plastic oil and 75% diesel oil
EGR	Exhaust gas recirculation
CR	Compression ratio

Materials and methodology

Pyrolysis process

Pyrolysis process is useful in converting waste plastic into the desired products in the form of liquid, gas or solid. Pyrolysis is a thermal degradation process which occurs in the absence of oxygen and produce the waste plastic oil by using silica alumina as a catalyst. Minimize the different sizes and shapes of waste plastic with the crushing, cutting or shredding and graded into uniform size for ease of handling in the melting process. The graded feed was stored in a hopper and dust or other finewastes collected from the cyclone filter are disposed through a vent with particle size monitoring system. The filtered waste plastic fed into the reactor along with 1-2% catalyst (by weight) and 8-10% coal (by weight).The temperature constantly maintained at the range of 350°C -450°Cat atmospheric pressure using a PID controllerfor about 3-4 hours. The outlet gas was condensed and obtained liquid taken as waste plastic oil fuel and uncondensed gases were let out into the atmosphere. This process gives a mixture of petrol, diesel and kerosene by weight 70-75%, 5-10% residual cokes and the rest is LPG.

II. EXPERIMENT SET-UP

The engine tests were performed on a 4-stroke,single cylinder, TV 1 model, water cooled diesel engine at 3.5 rated power with constant speed 1500 rpm. The engine specification are showed in table 2.

The investigation was carried out on the engine by using waste plastic oil blends with diesel.All the engine experiments were performed with speed, load, variation of compression ratio, waste plastic oil blends and air consumed were measured in each test.An eddy current dynamometer was used to load the engine, an air box was fitted for airflow measurement and An I.C Engine software 9 is used to measure the data obtained and all the data's are measured at variation of compression ratio. Engine investigates the performance parameters of waste plastic oil blends with diesel such as brake thermal efficiency, brake specific fuel consumption and exhaust gas temperature. An AVL 4000 Light Di-Gas Analyzer was used to measure HC, CO, CO_2 and NO_X emissions in the exhaust gas. Initially engine started with pure diesel oil B_0 and then the engine was run with waste plastic oil blends B_{10}, B_{15}, B_{20}, and B_{25} respectively with increasing compression ratio and load. For the prevention of engine nozzle the engine was run with diesel oil to flush out the waste plastic oil blends from the fuel measuring tube and the injection system at the end of the test.

Experiment Engine Set-up

Table 2 Test engine specifications.

Parameters	**Specifications**
Model and manufactures	TV1, kirloskar
Swept vol. and clearance vol.	661.45 and 38.9
No. of cylinders and strokes	1 and 4
Compression ratio	12 to 18:1
Bore and strokes	87.5 and 110
Speed and rated power	1500 and 3.5 kw
dynamometer	Eddy current dynamometer

III. RESULTS AND DISCUSSION

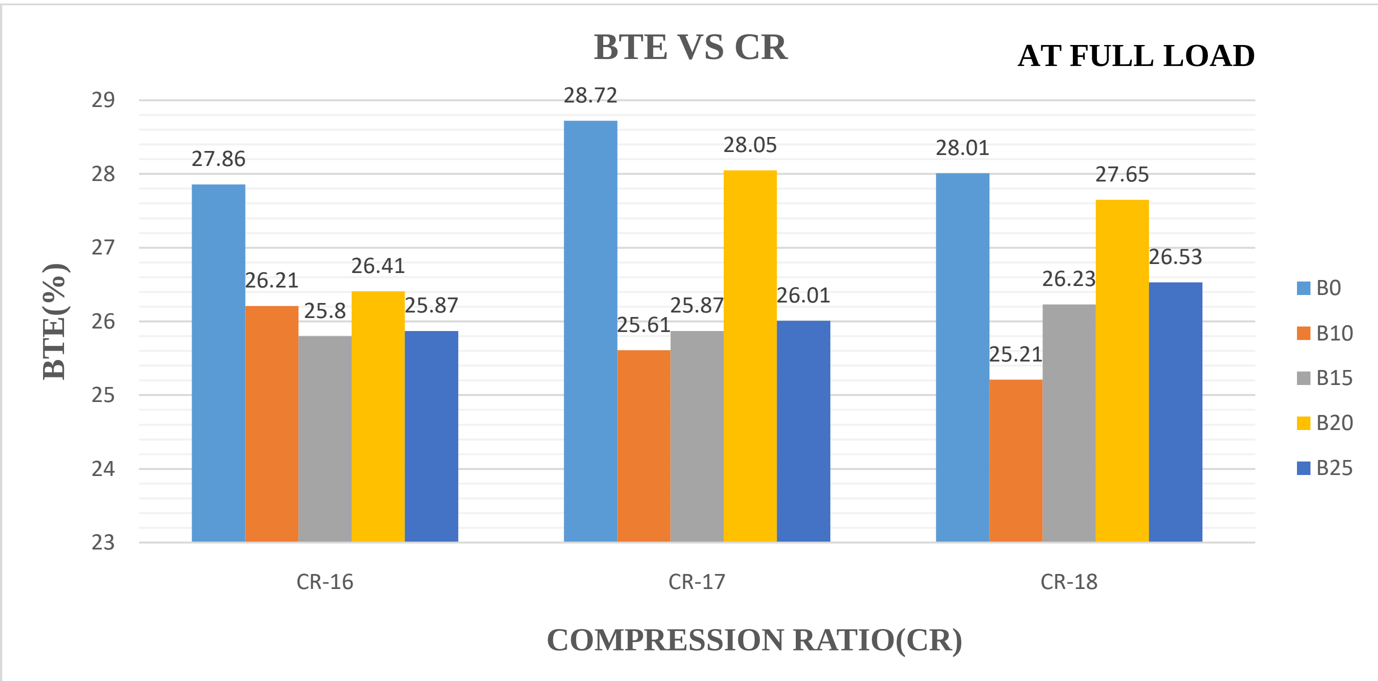
Table 3 Properties of fuel

S.N.	Blends	Density(g/ml)@15^{0}C	Kin.Viscosity(cst)@40^{0}C	Acid value (mgkoh/gm)	Calorific value (cal/gm)
1	Pure diesel	0.838	2.20	0.062.	10476
2	B0	0.864	2.67	0.050	9830
3	B10	0.826	2.42	0.062	10192
4	B15	0.832	2.49	0.071	10132
5	B20	0.840	2.60	0.082	10082
7	B25	0.852	2.62	0.088	9980
Test-	method	IS1448P-32	IS1448P-25	IS1448P-1/SEC-1	IS1448P-6

Performance characteristic

Brake thermal efficiency:

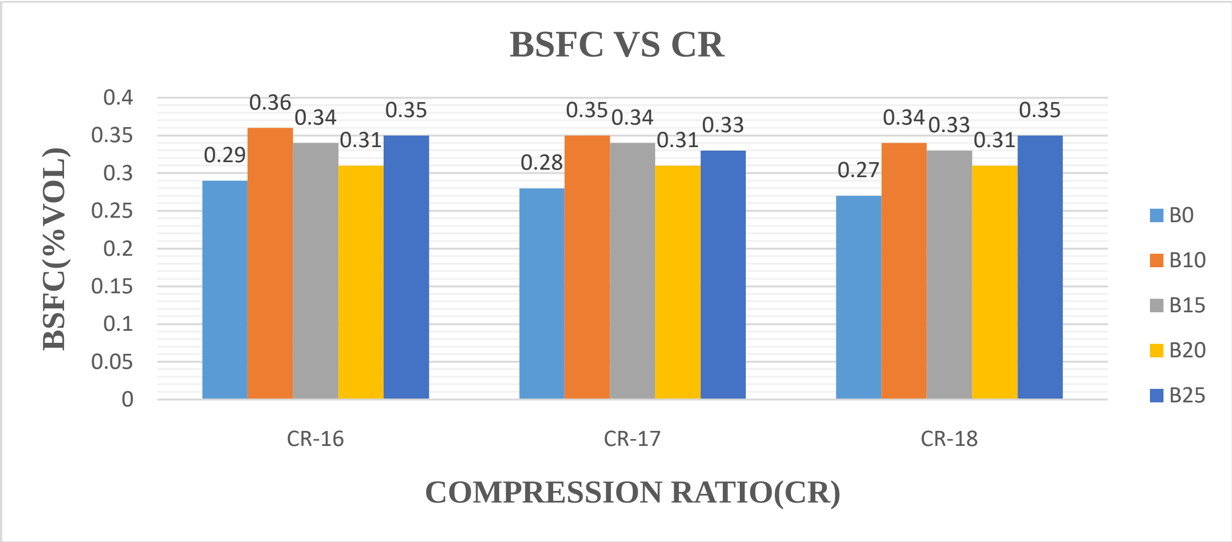
All the Results shows that the brake thermal efficiency is 28.72% for standard diesel and 28.05% for the waste plastic oil blends (B_{20}) at CR-17 at full load. At full load, the BTE of standard diesel is slightly higher because of lower calorific value, higher viscosity as well as higher density of waste plastic oil blends.The BTE of waste plastic oil blends (B_{20}) is closer to standard diesel up to 70%-75% of rated power, this is due toslightly higher exhaust gas temperature, heat release rate of waste plastic oil when compared to standard diesel. BTE is observed on a four stroke, single cylinder, water cooled,TV1 model 3.5 Kw diesel engine fueled with standard diesel oiland waste plastic oil blends such as B_0, $B_{10,}$ B_{15}, $B_{20,}$ and B_{25} is 28.72%, 25.61%, 26.67% 28.05%, and 26.01%respectively at full load with CR-17 (**Viswanath K. Kaimal and P. Vijayabalan et al, 2015**).Theproper amount of fuel burnt inside the combustion chamber is high when the CR is increased from 16 to 18 a slight increase in BTE is observed for the waste plastic oil blends $B_{20.}$



VARIATION OF BTE WITH CRAT FULL LOAD

Brake specific fuel consumption

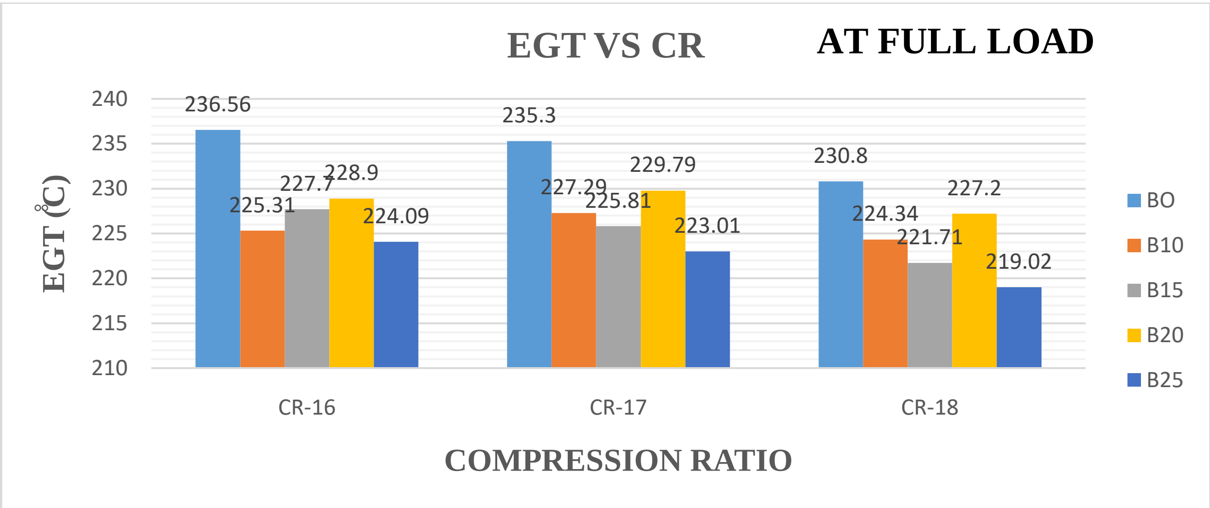
An experimental study on a four stroke, single cylinder, water cooled, TV1 model 3.5 Kw diesel engine, BSFC depends on the fuel supplied at inlet and work produce at outlet. BSFC is inversely proportional to thermal efficiency. The brake specific fuel consumption for the waste plastic oil varies from 0.693kg/kwh at no load to 0.31kg/kwhat full load for standard injection timing (**J. Devaraj et al, 2015)**.Resultsshows that the BSFC was found to increase with load for waste plastic oil blends B_{10}, B_{15} and B_{25}but blend B_{20} slightly increases as compared to the standard diesel oil. At full loadconditions, BSFC for standard diesel oil and waste plastic oil blends such as B_0, B_{10}, B_{15}, B_{20}, and B_{25} is 0.28kg/kwh, .35kg/kwh, .34kg/kwh, .31kg/kwh and .33kg/kwh respectively.The engine produces more brake power than an engine running at low CR.



VARIATION OF BSFC WITH CRAT FULL LOAD

Exhaust Gas Temperature

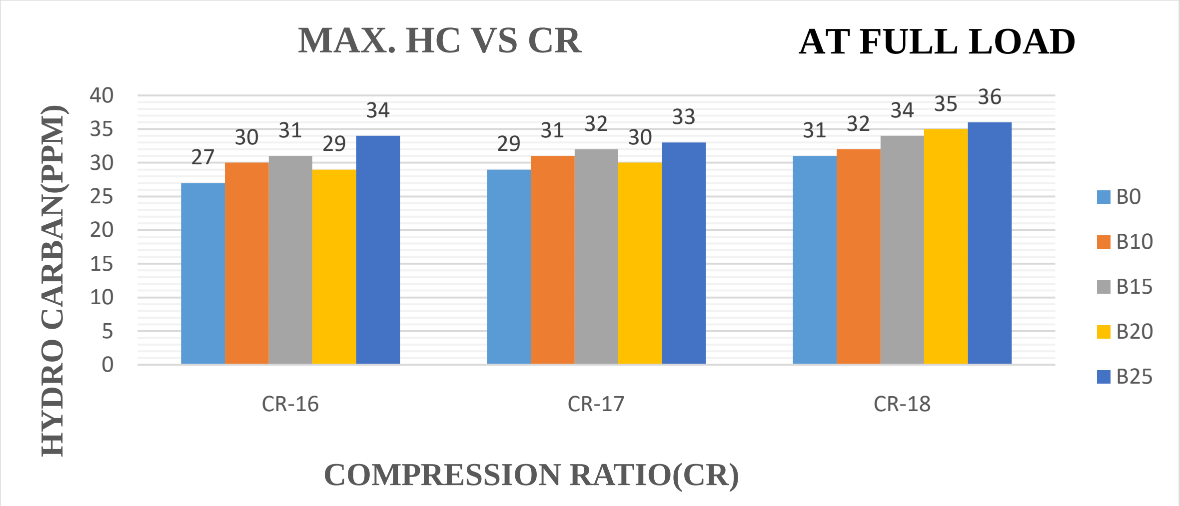
Experimental studywith increase in load on diesel engine, the cylinder pressure increases and more fuel is burnt leading to an increase in temperature of exhaust gases, i.e. exhausted from the engine cylinder (**Pawar Harshal R. and Lawankar Shailendra M. 2013**).Direct injection diesel engine shows that the exhaust gas temperature varies from 140°C at no load to 237°C at full loadfor standard diesel and its varies from 130°C at no load to 230°C at full load for waste plastic oil blends. Higher air fuel ratio is the results of increase in exhaust gas temperature with variation of engine load in case of waste plastic oil compared to the standard diesel at all load. At full load conditions, the exhaust gas temperature marginally higher for $B_{20}$is 230°C at CR-17.



VARIATION OF EGT WITH CRAT FULL LOAD

Unburned hydrocarbon.

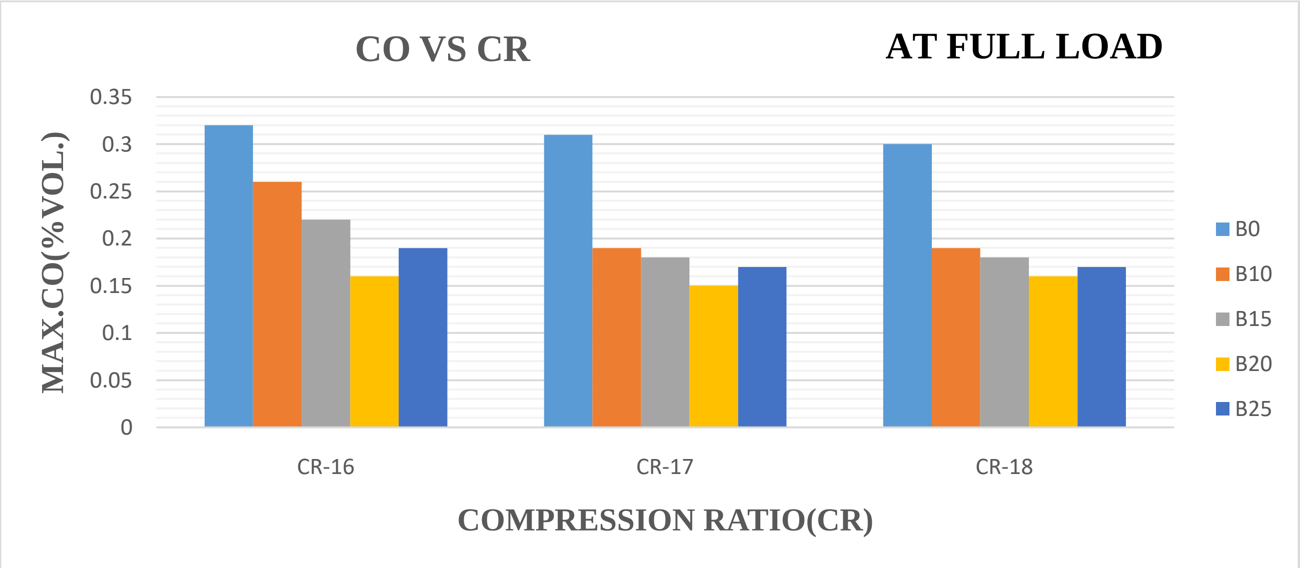
An experimental study shows that,unburned hydrocarbon varies from 16ppm at no load to 36ppm at full load for waste plastic oil blends and for standard diesel oil it is varies from 16ppm at no load to 31ppm at full load with variation of CR. It is noticed that the concentration of the hydrocarbon of waste plastic oil is higher than diesel because of higher fumigation rate and non-availability of oxygen relative to diesel. The whole reason behind increased unburned hydrocarbon for waste plastic oil blends is poor fuel distribution, large amounts of excess air and low exhaust temperature, fuel–air mixture regions relative to the standard diesel oil. In the case of waste plastic oil blends B_{20} it varies standard diesel oil at CR-17 (**Viswanath K. Kaimal and P. Vijayabalan et al, 2015**).



VARIATION OF UBHC WITH CRAT FULL LOAD

Carbon monoxide

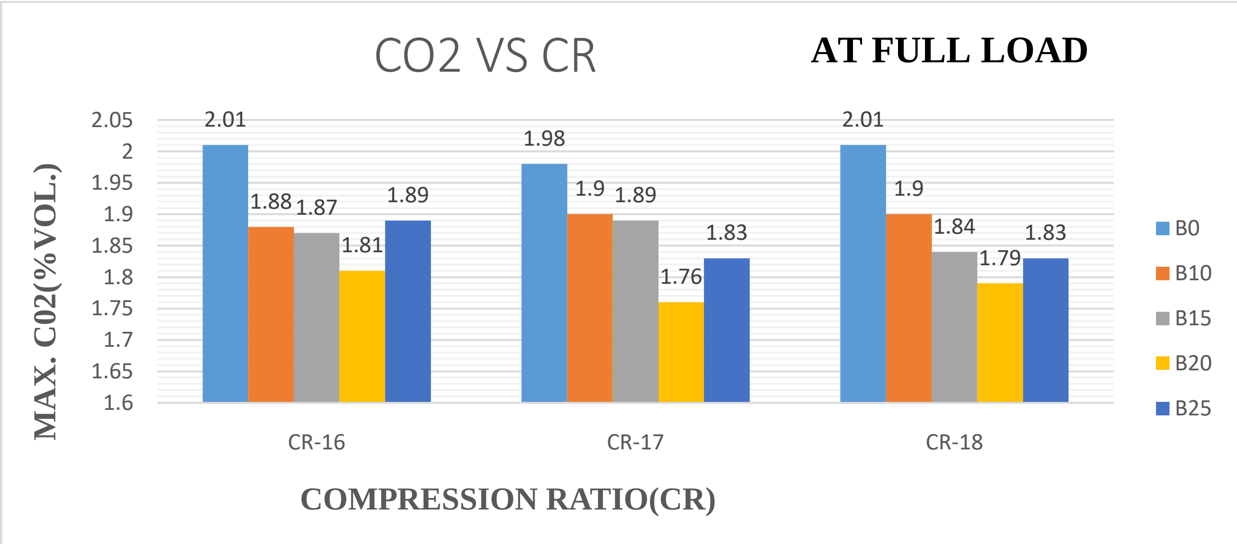
The carbon monoxide emission produces due to the lack of oxygen, poor air entrainment, mixture preparation and the incomplete combustion of fuel inside combustion chamber.Generally, diesel engine operates with lean air-fuel mixtures and hence the CO emission would be low but CO emission is toxic and must be controlled (**S. Prasanna Raj Yadav,2016**). The results shows that the concentration of CO varies from 0.55% vol. at no load to 0.17% vol. at full load for waste plastic oil blends and for standard diesel oil it is varies from 0.59% vol. at no load to 0.30% vol. at full load with variation of CR.So the CO emission of waste plastic oil is slightly less than diesel. At full load conditions, the CO emissions of standard diesel oil blends B_0 andfor all waste plastic oil blendsB_{10}, B_{15}, B_{20} and B_{25} are 0.31% vol., 0.19% vol., 0.18% vol., 0.15% vol. and 0.17% vol. respectively at CR-17.



VARIATION OF CO WITH CRAT FULL LOAD

Carbon dioxide

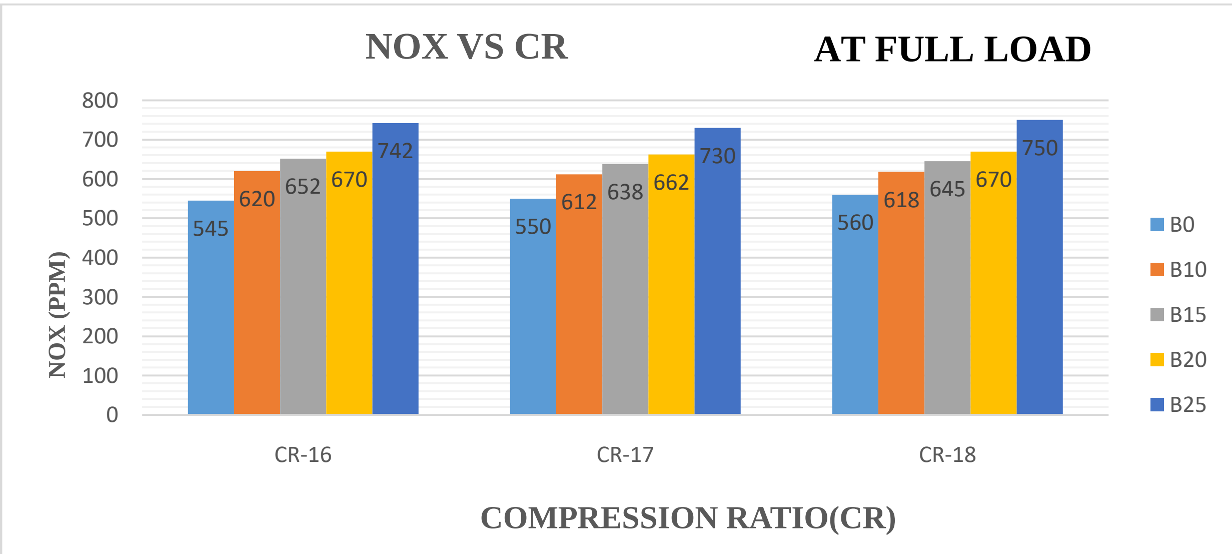
The CO_2 concentration varies from 1.01% vol. at no load to 2.01% vol. at full load for standard diesel oil and for waste plastic oil blends it is 0.8% vol. at no load to 1.9% vol. at full load with CR. So the CO_2 emission of waste plastic oil is slightly less than diesel. The results shows that, CO_2 concentration decreases with increase in EGR percentages which increase the CO concentration and decrease CO2 concentration, due to the instability in combustion and deficiency of oxygen (**H.K. Jeswani and A. Azapagic, 2016**). At the full load, the CO2 concentration in waste plastic oil blends B_{20} without EGR is found to be 770.85 g/kWh compared to 683 g/kWh with 20% EGR. At full load conditions, CO_2 concentration of standard diesel oil B_0 andwaste plastic oil blends $B_{10,}$ $B_{15,}$ B_{20} and B_{25} are 2.01% vol., 1.88% vol., 1.87% vol.,1.81% vol. and 1.89% vol. with CR-17.



VARIATION OF CO_2 WITH CRAT FULL LOAD

Nitrogen oxides

An experimental study on waste plastic oil and diesel fuel blends which is mainly depends on higher temperature presents in the exhaust gas.The reason for the increased NOx, inthe case of waste plastic oil blends is a higher aromatic content fuel with higher adiabatic flame temperature which results in higher heat release rate (**Tine Seljak et al, 2014**). Diesel engine indicate that, the concentration of NOx varies from 95ppm at no load to 560ppm at full load for standard diesel oil and from 129ppm at no load to 750ppm at full load for waste plastic oil blends. At full load, the variation of NO_XForstandard diesel oil B_0 and waste plastic oil blends $B_{10,}$ $B_{15,}$ B_{20} and B_{25} are 545ppm, 620ppm, 652ppm,670ppm and 742ppm respectively with CR-17.



VARIATION OF NO_X WITH CRAT FULL LOAD

IV. CONCLUSION

Performance characteristics of VCR diesel engine TV1 kirloskar 3.5kw, 4 strokes, single cylinder at 1500 rpm which is fueled with Waste plastic oil blends an inclusive investigation at different load and CR and the results are compared with the standard data obtained from pure diesel fuel. Which are denoted by the arrow.

- Brake thermal efficiency (BTE) for all the blends increases with increase in load and compression ratio because of better combustion at higher load and higher brake power obtained. At full load conditions, the BTE for the waste plastic oil blends at CR 17 are 28.05%, 26.01%, 25.87% and 25.61% whereas the BTE is slightly higher i.e.28.72% for diesel fuel at same load and CR-17.
- BSFC slightly decreases for all blends as compared to diesel fuel because of lower calorific value but BSFC for the blend B_{20} almost same at same load with same CR-17.
- The hydrocarbon emission increase with increase in load on engine but blend B_{20} gives less emission i.e. 30 ppm which are nearest to the standard diesel oil atresults in lower amount of oxygen available for the reaction.
- Thek. viscosity increases for all blends so the combustion of fuel some effected but blends B_{20} showed good results with compared to the standard diesel oil.
- Blend B_{20} shows better and compatible results than other blends or standard diesel oil.

All these blends when compared, it can be concluded B20 shows relatively more favorable and economical behavior when compared with other blends or standard diesel oil.

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