iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: V Month of publication: May 2022

DOI: https://doi.org/10.22214/ijraset.2022.43518

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue V May 2022- Available at www.ijraset.com

Optimization of Operating Parameters for Tyre Pyrolysis Oil Blended Single Cylinder Diesel Engine

P M Bhatt
Mechanical Department, Gujarat Technological University, Government Polytechnic, Himatnagar, Gujarat, India

Abstract: Increasing industrialization and motorization led to a significant rise in demand for petroleum products. As these are the non renewable resources, it is difficult to predict the availability of these resources in the future resulting in uncertainty in its supply and price and impacting growing economies like India, importing 80% of the total demand of the petroleum products. Many attempts have been made by different researchers to find out alternate fuels for Internal Combustion engines. Many alternate fuels like Biodiesel, LPG (Liquefied Petroleum Gas), CNG (Compressed Natural Gas) and Alcohols are being used nowadays by different vehicles. In this context pyrolysis of scrap tyres can be used effectively to produce oil, thereby solving the problem of waste tyre disposal. In the present study Experimental investigations were carried out to evaluate the performance and emission characteristics of a single cylinder diesel engine fuelled by TPO10, TPO15, and TPO20 keeping the blend quality by controlling density and viscosity of tyre pyrolysis oil within permissible limit of euro IV diesel requirement to study its replace ability. The investigation involves three parameters such as blend proportion, injection timing and injection pressure, a simultaneous optimization method called Taguchi was used in this work. This method requires fewer numbers of trials for fixing optimum levels. As per this method nine experiments were required to be conducted and the results were used for optimization. This is the primary advantage as well as disadvantage of this method. In order to eliminate this difficulty and improve the quality of the research work, twenty-seven experiments were conducted in this work and the results were used for optimization. In addition, an ANOVA was also performed for the parameters to evaluate its percentage contribution over the desired output. Using the optimum levels, a full range experiment was conducted to compare its performance and emission behaviour with standard diesel operation.
Keywords: Operating parameters, Diesel Engine, Tyre Pyrolysis Oil (TPO), Performance, Emission

I. INTRODUCTION

Petroleum based fuels are stored fuels in the earth. There are limited reserves of these stored fuels and they are irreplaceable. This finite resource of petroleum are highly concentrated in certain regions of the world, have given rise to uncertainty in its supply and price and is impacting growing economies like India, importing 80% of the total demand of crude. India's petroleum product consumption has increased from 100.4 million tons in 2001-02 to 133.4 million tons in 2008-09 at a CAGR of 4.1% and is likely to increase up to 217 million tons by 2020-21 and 325.6 million tons by 2030-31. All over the world, there are initiatives to replace gasoline and diesel fuel due to the impact of the fossil fuel crisis and hike in oil price. Millions of dollars are being invested in the search for alternative fuels.

On the other hand, the disposal of waste tyres from automotive vehicles is becoming more and more complex. Waste to energy is the recent trend in the selection of alternate fuels. Fuels like alcohol, biodiesel, liquid fuel from plastics, etc. are some of the alternative fuels for the internal combustion engines. In order to prevent waste rubber and in particular discarded automobile tyres from damaging the environment, it is highly desirable to recycle this material in a useful manner. However, the total quantity of tyres currently recycled in a given year (excluding reuse, retreading, or combustion) is less than 7% of the annual tyre generation rate in the world.

The use of tyre pyrolysis oil as a substitution of diesel fuel is an opportunity in minimizing the utilization of the natural resources. Several research works have been carried out on the pyrolysis of waste automobile tyres. Pyrolysis is the process of thermally degrading a substance into smaller, less complex molecules. Pyrolysis produces three principle products: such as pyrolytic oil, gas and char. The quality and quantity of these products depend upon the reactor temperature and design. In the Pyrolysis process, larger hydrocarbon chains break down at certain temperatures in the absence or a limited supply of oxygen that gives end products usually containing solids, liquids and gases. If the temperature is maintained at 550 ºC, the main product is a liquid, which could be a mixture of various hydrocarbons depending on the initial composition of the waste material [1, 3, 4, 12, 19].

TABLE I
Comparison of Properties of refined TPO with standard value for Diesel

SR. NO.	SPECIFICATIONS	TEST METHOD ASTM	UNITS	TEST RESULTS	STANDARD VALUE OF DIESEL (IS:1460)
1	KINEMATIC VISCOSITY AT 40^{O} C	P:25	cSt	2.30	2.0 - 4.5
2	ACIDITY, INORGANIC	P:2	mgKOH/gm	NIL	NIL
3	ASH	P:4	% by mass	0.01	0.01 MAX
4	FLASH POINT, ABLES/PMCC	P:20/ P:21	^{o}C	<30	35MIN/ 66MIN..
5	WATER CONTENT	ISO 12937	mg/kg	NIL	200 MAX
6	POUR POINT	---	^{o}C	+3	3 Min
7	DENSITY AT 15^{O} C	P:16	kg/cm^{3}	0.820	0.820-0.845
8	SEDIMENTS	P:30	Mg/100ml	NIL	---
9	TOTAL SULPHUR	ISO 20846	mg/kg	0.35	50 MAX
10	CARBON RESIDUE, RAMSBOTTOM	P:8	%	0.25	0.30 MAX
11	COPPER STRIP CORROSION TEST FOR 3 HRS AT 100^{O} C	P:15	---	1a	<1
12	DISTILATION, RECOVERY OF 92% AT ^{O}C	P:18	^{O}C	360	360 MAX
13	COLOUR INDEX	---	---	5	TO REPORT
14	CETEN NUMBER, DIESEL INDEX	P:9	---	44	51 MIN.
15	ACIDITY, TOTAL	P:2	mgKOH/gm	NIL	TO REPORT
16	POLYCYCLIC AROMATIC HYDROCARBON	P:39	% by mass	7	11

Pyrolysis of scrap tyres produces oil that can be used as liquid fuel for industrial furnaces, foundries and boilers in power plants due to their higher calorific value, low ash, and moisture content as far as Sulphur content of oil is not a problem. However higher density, Kinematic viscosity and Lower Cetane number of tyre oil suggests that behaviour of tyre oil in Internal Combustion Engine can be studied by improving its quality in terms of reduction in density, viscosity, Sulphur and aromatic contents by proper distillation and processing of tyre oil, if tyre oil is to be used as a fuel in Internal Combustion Engine. In order to better analyse potential use of tyre pyrolysis oil as a substitute to diesel fuel, ASTM distillation of the oil was carried out and the refined oil was tested in the laboratory for determination of its physico-chemical properties as compared to standard value for diesel as shown in the table -1. From the table it is clear that almost all the properties of refined tyre oil is more or less within permissible limit of Euro IV diesel specifications except flash point and Cetane number, which suggests that behaviour of tyre oil in Internal Combustion Engine can be studied through blending Tyre oil with DF on volume basis. In the present work 10 %, 15%, and 20%, of TPO is blended with DF on volume basis and observed for 15 days to check for any separation. No such separation was noticed. TPO blended with DF is indicated as TPO xx. For example, 10 % TPO blended with 90 % DF is denoted as TPO 10.

II. EXPERIMENTAL DETAILS

In the present work single cylinder water cooled diesel engines as shown in figure 1 is used for studying the performance and emission characteristics of the TPO - DF blend. The specifications of the engine are shown in table 2.

Fig. 1 Single cylinder diesel engine test rig

TABLE II
ENGINE DETAILS

Name of the Engine	Captain
General Details	Four stroke, CI, Water cooled, Single Cylinder
Rated Power kw/bhp	3.7/5.0
Rated Speed(rpm)	1500
Bore(mm)	87.5
Stroke(mm)	110
Compression Ratio	16.5:1
Dynamometer	Eddy current, water cooled with loading
Fuel oil	HSD
Lubricant	SAE 30/40

The fuel flow rate was measured on a volumetric basis using a burette and a stop watch. The air flow rate was measured by connecting the air intake to a large rigid box with an orifice at its inlet to damp out pulsations in flow and by measuring the pressure drop across orifice by means of the water tube manometer. Thermocouple with K type probe having temperature range 0-1200^{0}C and accuracy 0.4% of the reading above 0^{o}C in conjunction with a digital temperature indicator was used to measure the exhaust gas and cooling water temperature. Sling Psychrometer was used to measure dry bulb and wet bulb temperature of the surrounding. Laser photo tachometer having 5 digits, 10 mm LCD display and range 10 to 99,999 RPM with accuracy ±0. 05% + 1 digit was used for speed measurement. A Non dispersive Infrared 4-gas analyzer was used to measure emissions in the exhaust. CO was measured in percentage volume. HC was measured in ppm volume. Smoke opacity was measured using a diesel smoke meter. All the tests were conducted by starting the engine with DF only. After the engine was warmed up, it was then switched to TPO-DF blend. At the end of the test, the fuel was switched back to diesel and the engine was kept running for some time to flush out the TPO-DF blend by DF from the fuel line and the injection system, in order to prevent the fuel system from the accumulation of TPO-DF which may damage the system.

III. TAGUCHI'S METHOD OF OPTIMIZATION

Taguchi is used for optimization of the operating parameters involved in the experiment with less number of trials. This method uses an orthogonal array to study the entire parameter space. To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between design parameters that need to be made. [24] The present study uses three factors at three levels (Table 3).

Table III
Process Parameters and Their Levels

Symbol	Parameters	Unit	Level 1	Level 2	Level 3
A	Injection Timing	CA BTDC	26	28	30
B	Injection Pressure	bar	180	190	200
C	Blend	% TPO	10	15	20

Hence, an L_9 orthogonal array with three columns and nine rows should be used for the construction of experimental layout for implementing Taguchi method. This is found to be a major drawback of this method since L_9 orthogonal array can not test all possible variable combinations. In order to eliminate this difficulty and improving the quality of the research work, twenty seven experiments were conducted in this work and the results were used for optimization. L_{27} has three columns and twenty seven rows and the parameters such as injection timing (A), injection pressure (B) and blend proportions (C) at various levels were arranged in three columns and twenty seven rows as shown in table 4. According to this layout, twenty seven experiments were designed and trials were selected at random, to avoid systematic error creeping into the experimental procedure. For each trial the brake thermal efficiency was calculated and used as a response parameter. Taguchi's method uses a parameter called signal to noise ratio (S/N) for measuring the quality characteristics. There are three kinds of signal to noise ratios are in practice. Of which, the higher-the-better S/N ratio was used in this experiment because this optimization is based on higher BTE. After the determination of optimum level of parameters, a full range experiment was conducted using the selected blend at the optimum engine setting. This is mainly to compare the performance and emission characteristics of Tyre pyrolysis oil-diesel blend with standard diesel operation. An ANOVA was also performed for the involved parameters to check the percentage contribution of parameters over the desired response. [24]

TABLE IV
LAYOUT OF L_{27} ORTHOGONAL EXPERIMENTS

A	B	C
26	180	10
26	190	10
26	200	10
26	180	15
26	190	15
26	200	15
26	180	20
26	190	20
26	200	20
28	180	10
28	190	10
28	200	10
28	180	15
28	190	15
28	200	15
28	180	20
28	190	20
28	200	20

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue V May 2022- Available at www.ijraset.com

30	180	10
30	190	10
30	200	10
30	180	15
30	190	15
30	200	15
30	180	20
30	190	20
30	200	20

IV. OPTIMIZATION OF OPERATING PARAMETERS

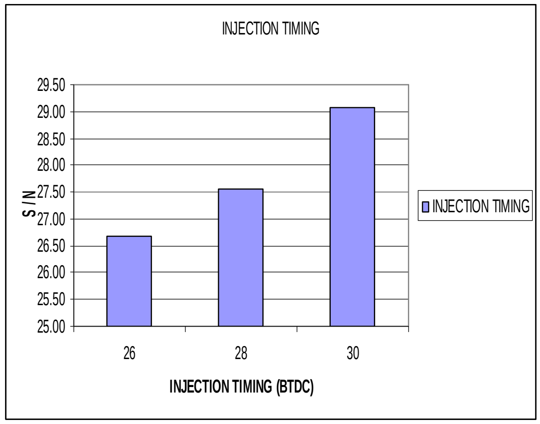
Table 5. Shows S/N ratios for brake thermal efficiencies obtained while performing various experiments.

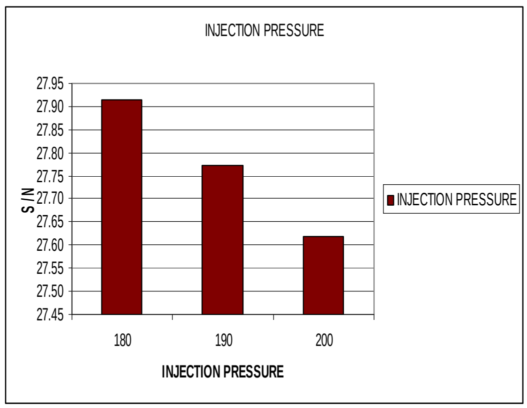
Table V
S/N RATIO TABLE FOR RESPONSE PARAMETER

A	B	C	S/N Ratio
26	180	10	26.73
26	190	10	26.73
26	200	10	26.73
26	180	15	26.73
26	190	15	26.73
26	200	15	26.83
26	180	20	26.50
26	190	20	26.62
26	200	20	26.51
28	180	10	27.26
28	190	10	27.89
28	200	10	27.79
28	180	15	28.95
A	B	C	S/N Ratio
28	190	15	27.78
28	200	15	27.78
28	180	20	27.47
28	190	20	27.04
28	200	20	25.98
30	180	10	29.16
30	190	10	28.63
30	200	10	27.89
30	180	15	29.16
30	190	15	29.91
30	200	15	30.65
30	180	20	29.27
30	190	20	28.63
30	200	20	28.42

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue V May 2022- Available at www.ijraset.com

Figure2. Shows the response graph of Taguchi experiment. It was used for selecting the optimum level of the parameters. The peak value of each graph is considered as the optimum points as these points are offering highest S/N ratios.





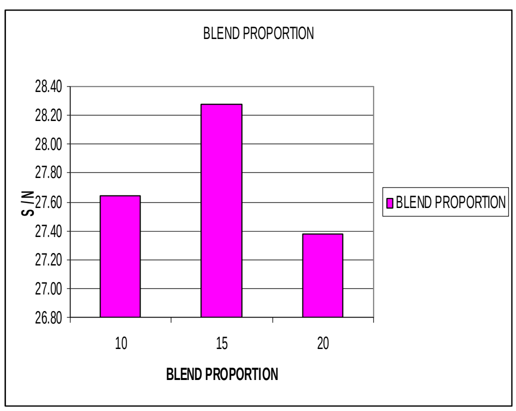


Fig. 2 MAIN EFFECTS

The optimum points obtained from the response graph is listed in Table 6. These optimum parameters were used for the full range experiment.

Table VI
OPTIMUM PARAMETERS

Parameters	Injection timing	Injection pressure	Blend proportion
value	30^{o} BTDC	180 bar	TPO15

V. ANALYSIS OF VARIANCE

The purpose of analysis of variance (ANOVA) is to investigate the influence of individual factors and influence of factors other than those included in the study. Table 7 indicates the percentage contribution of various parameters involved in Taguchi experiments.

Table VII
ANOVA TABLE

Factor	DOF (f)	Sum of sqrs (s)	Variance (V)	F Ratio (F)	Pure sum (s')	Percentage P (%)
Inj. timing	2	12.32	6.16	187.93	12.25	75.01
Inj. press.	2	1.44	0.72	22.04	1.37	8.44
Blend	2	2.50	1.25	38.20	2.43	14.93
Other	2	0.065	0.032			1.607
Total	8	16.336				100%

A parameter called Injection timing has the highest contribution over output characteristic whereas the injection pressure has the lowest contribution compared to other two parameters. This means that the change of injection pressure has insignificant effect over the output characteristics. Using the optimum parameters achieved by Taguchi's method of optimization a full range experiment was conducted and its results were compared with diesel fuel operation.

VI. RESULTS AND DISCUSSIONS

A. *Performance Characteristics*

1) *Brake Thermal Efficiency*

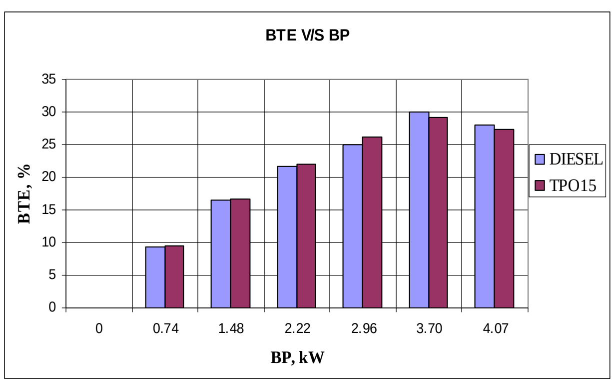


Fig. 3 VARIATION OF BRAKE THERMAL EFFICIENCY WITH BREAK POWER

Figure 3 shows the comparison of the brake thermal efficiency with brake power for the tested fuels. It can be seen from the graph that thermal efficiency of TPO15 is higher than diesel fuel up to 80% load however at full load it is marginally less than that of diesel fuel but quite comparable with that of diesel fuel. This may be due to proper mixing and combustion of refined TPO15 with DF. Another possible reason may be that, after refining, the calorific value of TPO increases as compared to raw TPO due to elimination of impurities, moisture, carbon particles, sediments and Sulphur and reaches up to the value that is quite comparable to diesel.

2) Specific Energy Consumption

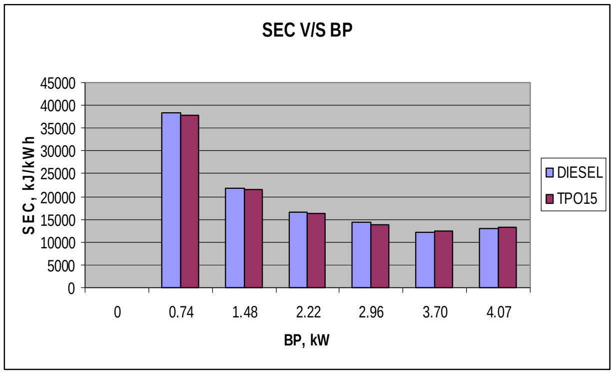


Fig. 4 Variation Of Specific Energy Consumption With Break Power

Figure 4 shows the comparison of the specific energy consumption with brake power for the tested fuels. It can be seen from the graph that specific energy consumption of TPO15 is lower than diesel fuel up to 80% load however at full load it is marginally higher than that of diesel fuel but quite comparable with that of diesel fuel. This behaviour is obvious since the engine will consume more or less same amount of fuel to gain the same power output due to quite comparable calorific value of TPO15 with that of Diesel Fuel.

3) Exhaust Gas Temperature

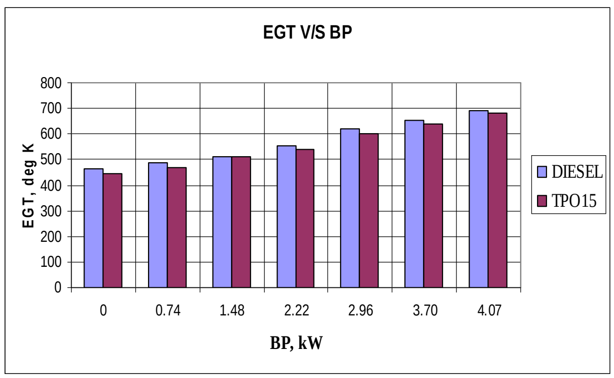


Fig. 5 Variation Of Exhaust Gas Temperature With Break Power

Figure 5 shows the variation of exhaust gas temperature with brake power for the tested fuels. It can be seen from the graph that Exhaust gas temperature of TPO15 is lower than diesel fuel at all the loads. The reasons for lower exhaust gas temperatures for TPO 15 blend are due to better atomization and vaporization of fuel due to lower viscosity.

B. Emission Characteristics

1) Carbon Monoxide

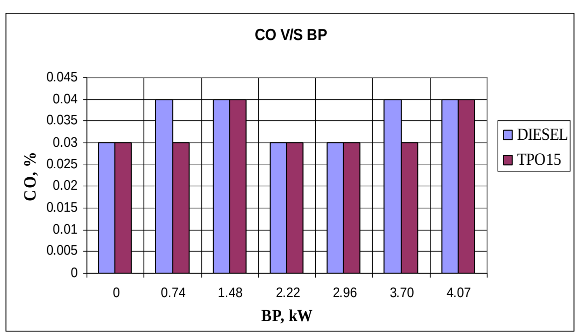


Fig. 6 VARIATION OF CO EMISSION WITH BREAK POWER

Figure 6 shows the comparison of Carbon monoxide emission with brake power for tested fuels. Generally, CI engines operate with lean mixtures and hence the CO emission would be low. CO emission for the TPO15 is almost constant at about 0.03% from no load to full load. The concentration varies from 0.03% at no load to 0.04% at full load for DF. Lower values of CO can be attributed to the proper mixture formation and efficient combustion due to lower viscosity and better volatility of TPO15.

2) Hydrocarbon

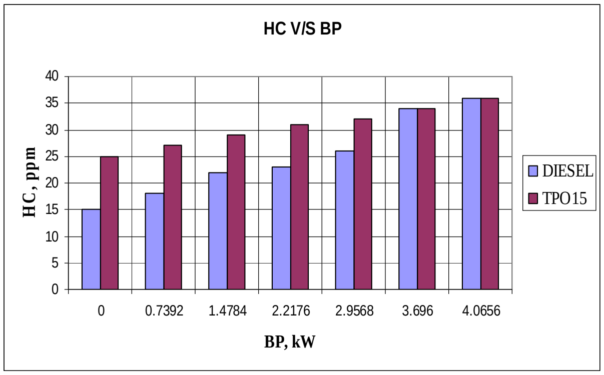


Fig. 7 Variation Of Hydrocarbon Emission With Break Power

Figure 7 shows the comparison of Hydrocarbon emission with brake power in the exhaust for the tested fuels. Unburnt hydrocarbon emission is the direct result of incomplete combustion. It is apparent that the hydrocarbon emission is increasing with increase in load for TPO15 as well as DF. HC varies from 15 ppm at no load to 36 ppm at full load for DF, and it varies from 25 ppm at no load to 37 ppm at full load for TPO15. HC is considerably higher at no load probably due to significant ignition delay in DI engine, further the fuel spray does not propagate deeper into the combustion chamber and gaseous hydrocarbons remain along the cylinder wall and the crevice volume and left unburned. The other one is unsaturated hydrocarbons present in TPO which are unbreakable during the combustion process [25] as well as higher aromatic content of tyre pyrolysis oil but it is quite comparable with that of diesel at full load.

3) *Smoke Opacity:* Figure 8 shows the comparison of Smoke opacity with brake power in the exhaust for the tested fuels. Smoke from the diesel engine originates as well as increases due to high temperatures in fuel rich side of reaction zone in the diffusion combustion phase. It is apparent that the smoke opacity varies from 13.80% at no load to 33.80% at full load for DF, and it varies from 8.80% at no load to 27.5% at full load for TPO15. From the comparison it is clear that smoke opacity is considerably lower at

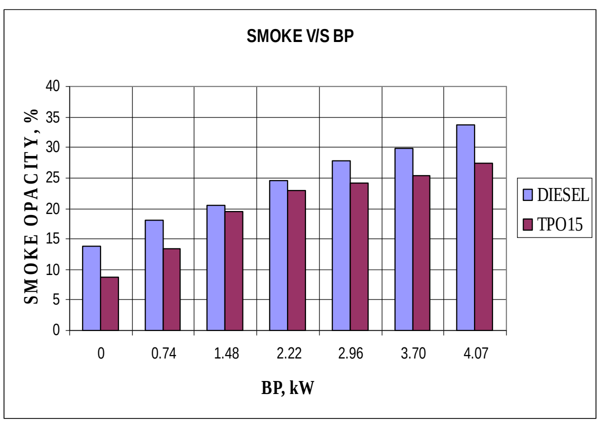


Fig. 8 Variation Of Smoke Opacity With Break Power

all the load conditions for TPO15 as compared to DF, may be due finer fuel spray as well as higher temperatures during expansion stroke and more time for oxidation of soot particles due to advancing the injection timing.

VII. CONCLUSIONS

Based on the experimental investigations conducted on a single cylinder DI diesel engine using Tyre pyrolysis oil mixed diesel fuel, the following major conclusions are arrived.

1) Optimum level of parameters found by implementing Taguchi method and 15% TPO blend is found to be working satisfactorily at optimum setting, No oil sticking or injector choking was found during the experiments.
2) The results showed that the mixing of Tyre pyrolysis oil with diesel fuel up to 15% results in higher Brake thermal efficiency than diesel fuel up to 80% load however at full load it is marginally less but quite comparable with that of diesel fuel.
3) HC emission is significantly higher at no load, may be due to higher ignition delay at no load but as the load increases rate of rise of emission of HC for TPO15 decreases gradually as compared to diesel and is found to be quite comparable at full load at optimum setting.
4) Approximately 22.5% smoke reduction was achieved with TPO15 operation at full load for optimum level of parameters.

Within the extent of the present work, it is concluded that TPO15 can be used as a partial substitute for diesel.

REFERENCES

[1] Cunnliffe. A.M., Williams. P.T. “Composition of oil derived from the batch pyrolysis of tyres”, Journal of Analytical and Applied Pyrolysis 44, October 1997, pp.131-152.
[2] Williams. P.T, Bottril. R.P, Cunliffe. A.M, “Combustion of tyre pyrolysis oil”, Trans IChme, Vol 76, Part B, November 1998.
[3] Roy C., Chaala A. and Darmstadt H “The Vacuum Pyrolysis of Used Tyres End use of oil and carbon black product”, Journal of Analytical and Applied Pyrolysis 51, November 1998, pp. 201-221.
[4] Rodriguez I.M, Laresgoiti M.F, “Pyrolysis of scrap tyres”, Fuel Processing Technology 72,February 2001, pp. 9-22
[5] Moran A, Díez C, Martinez L.F “Pyrolysis of tyres, Influence of final temperature of the process on emissions and calorific value of the products recovered”, Waste Management 24, November 2003, pp. 463-469
[6] Huang Kuo-Lin, Chen Shui-Jen, “Emissions of Polycyclic aromatic hydrocarbons from the pyrolysis of scrap tyres”, Atmospheric Environment 41, September 2006, pp. 1209-1220
[7] Wang Tiejun, Zhang Xinghua “Vacuum pyrolysis of scrap tyres with basic additives”, Waste Management 28, December 2007, pp. 2301-2310
[8] Felix A. Lopez, Teresa A.Centeno “Distillation of scrap tyres in a pilot plant”, Journal of Hazardous Material 190, March 2011, pp. 285-292
[9] Laresgoiti M. F., Macro I. de, Torres A, Caballero B, Cabrero M.A, and Chomon M.J, "Chromatographic analysis of the gases obtained in tyre pyrolysis," Journal of Analytical and Applied Pyrolysis, Vol 55, 2000, pp. 43-54
[10] Kaminski C and Mennerich C, "Pyrolysis of synthetic tyre rubber in a fluidized-bed reactor to yield 1,3-butadiene, styrene and carbon black," Journal of Analytical and Applied Pyrolysis, vol. 58-59, 2001, pp. 803-811
[11] Berrueco C, Esperanza E, Mastral F.J, Ceamanos J and García-Bacaicoa P, "Pyrolysis of waste tyres in an atmospheric static-bed batch reactor: Analysis of the gases obtained," Journal of Analytical and Applied Pyrolysis, vol. 74, 2005, pp. 245-253
[12] Ucar S, Karagoz S, Ozkan A.R, and Yanik J, “Evaluation of two different scarp tyres as hydrocarbon source by pyrolysis," Fuel, vol. 84, 2005, pp. 1884-1892,
[13] Kyari M, Cunliffe A, Williams P T, "Characterization of oils, gases, and char in relation to the pyrolysis of different brands of scrap automotive tyres," Energy & Fuels, vol. 19, 2005, pp. 1165-1173
[14] Leung D.Y.C, Yin X.L, Zhao Z.L, Xu B.Y, Chen Y, "Pyrolysis of tyre powder: influence of operation variables on the composition and yields of gaseous product," Fuel Processing Technology, vol 79, 2002, pp. 141-155
[15] Williams P T and besler S, “Pyrolysis- thermograimetric analysis of tyres and tyre components”, Fuel. 74, 1995, pp. 1277-1283,
[16] Li S.Q, Yao Q, Chi Y, Yan J.H, Cen K F, "Pilot-scale pyrolysis of scrap tyres in a continuous rotary kiln reactor," Industrial & Engineering Chemistry Research, vol.43, 2004, pp. 5133-5145,
[17] Díez C, Sánchez M.E, Haxaire P, Martínez O, Morán A, "Pyrolysis of tyres: A comparison of the results from a fixed-bed laboratory reactor and a pilot plant (rotary reactor)," Journal of Analytical and Applied Pyrolysis, vol. 74, 2005, pp. 254-258.
[18] Conesa J.A, Martin-Gullon I, Font R, Jauhiainen J, "Complete study of the pyrolysis and gasification of scrap tyres in a pilot plant reactor," Environmental Science & Technology, vol. 38, 2004, pp. 3189-3194,
[19] Merchant, Petrich M.A, "Pyrolysis of scrap tyres and conversion of chars to activated carbon," AIChE Journal, vol. 39, 1993, pp. 1370-1376
[20] Roy C and Unsworth J, “Pilot plant demonstration of used tyres vacuum pyrolysis.” London: Elsevier Applied Science, 1989.
[21] Kawakami S, Inoue K, Tanaka H, Sakai T, “Pyrolysis process for scrap tyres, in: J.L. Jones, S.B. Radding (Eds.), Thermal Conversion of Solid Wastes and Biomass”, ACS Symposium Series 130, American Chemical Society Publishers, Washington DC, 1980.
[22] Tamilvendhen D, Ilangovan V, Karthikeyan R, "Optimization of engine operating parameters for Eucalyptus oil mixed diesel fueled D I Diesel engine using Taguchi Method" ARPN Journal of Engineering and Applied Sciences, vol. 6, NO. 6, June 2011.
[23] Nagarajan G, Rao A.N, Renganarayanan S, “Emission and performance characteristics of neat ethanol fuelled DI diesel engine” International Journal of Ambient Energy., 2002, pp 149-158. WEBSITE:
[24] Oracle World wide, “ recycle the possibilities are endless” , August 2011, http://www.oracleworldwide.net/download/Details-of-waste-tyre-recycling-plant-Project-Report-25.html
[25] Eco Energy Solutions, “ Power Generation by Scrap Tyres”, January 2011, http://ecoenergysolutions.co.in/pdf/Pre project Report for Waste Tyre to Energy. PDF (f)
[26] "http://en.wikipedia.org/.
BOOKS
[27] Basu Prabir, Biomass Gasification and Pyrolysis Practical Design, Elsevier Inc., 2010, pp 67-69.
[28] Heywood J B, Internal combustion engines fundamentals, McGraw Hill Publications, 1988.