ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

Performance Analysis of CI Engine Using Tire Pyrolytic Oil Diesel Blend

Kundan Kumar[1*], Amit Kumar[1], Dheeraj Kumar[1], and Apurba Layek[1]

[1] Department of Mechanical Engineering, National Institute of Technology Durgapur, India

Abstract

Waste scrap tires are becoming a severe pollution threat in terms of solid waste management and waste disposal. It is difficult to reuse or recycle waste scrap tires without any thermal or mechanical treatment beacause of their thermo-mechanical properties and their non-biodegrability. On the other hand, energy demand has increased and will keep on growing, especially in developing nations where energy is required for economic growth and poverty mitigation. Pyrolysis process is one of the best techniques in this context. Waste to energy conversion is the basic idea of this technology. The present study focuses on the production of waste tire pyrolytic oil (WTPO) and the performance of diesel engine using WTPO diesel blend. Small pieces (2-3 cm) of waste tires were subjected to pyrolysis process at a temperature range 430-550°C and 24°C/min heating rate and converted into crude WTPO. Further, this crude WTPO was subjected to the distillation process in the temperature range 180-220°C and a light fuel similar to diesel fuel was obtained, which was orange in color. Observations were made on different temperature ranges for the distillation process. Further, this WTPO was blended with diesel oil at 5, 10, 15, and 20% blend ratios and tested on a manually operated, four-stroke, single-cylinder, and water-cooled diesel engine for the performance analysis. It was found that the waste tire has great potential so that it can be used as an alternative source of diesel.

Keywords: waste tire, WTPO, diesel engine, pyrolysis process, pyrolytic tire oil

1. Introduction

Energy demand will keep on increasing, especially in developing nations where energy is required for economic growth. On the other hand, pollution is also becoming a global issue. About 60% of waste tires end up being dumped, causing land pollution in urban and rural areas **[13]**. This huge amount of waste scap tires cannot be reused or recycled directly. It requires some thermal and mechanical treatment to do so. This is beacause of their non-biodegradibility and thermo-mechanical properties **[9]**.

Preferable machines that convert chemical energy to mechanical energy are diesel engines. Transportation and automobile depend mostly on liquid fuel. So diesel and petrol are important fuels for the purpose. We cannot imagine the transportation in the world without these fuels.

Depletion of conventional sources of energy, increasing demand for energy, and solid waste due to tires causing a serious problem. The high calorific value of tires (35-40 MJ/kg) and a considerable amount of carbon black makes these tires suitable for the conversion into liquid fuels **[11]**. Pyrolysis is the best way to convert these waste tires into liquid fuels **[7]**. Pyrolysis is the thermal degradation of organic materials at some elevated temperature in the absence of oxygen, resulting in three product oil, gas, and char. Oil consists of C5-C20 hydrocarbons that can be used as an alternative fuel, gas consists of C1-C4 hydrocarbon having high calorific value, and char can be used as carbon black **[5]**.

In this study, single-cylinder, four-stroke, diesel engine was utilized for the analysis of waste tire pyrolytic oil (WTPO) – diesel blend using rope brake dynamometer.

Lastly, for a few decades, many researchers have given their effort in diesel engines for the pyrolysis of tires. In research, it has been observed that on varying the percentage of tire pyrolysis oil 10%, 30%, and 50%. This oil percentage is blended with diesel fuel in a diesel engine of the single-cylinder direct injection system. It has been observed in this experimentation that in diesel engines, tire pyrolysis oil can be successfully be used in the future.**[14]** Another study has been made possible by varying the opening pressure of nozzle, and different compression ratio at optimized injection timing in a diesel engine. A mixture of biodiesel fuel and pyrolysis oil obtained from waste tires. The percentage was 80% and 20%, respectively, of biodiesel fuel and pyrolysis oil **[15].**

2. Experimental setup

2.1 Crude WTPO

Pyrolysis process was carried out for conversion of scrap tires into waste tire pyrolytic oil (WTPO). This process can be understood by the schematic diagram shown in **Fig. 1**.

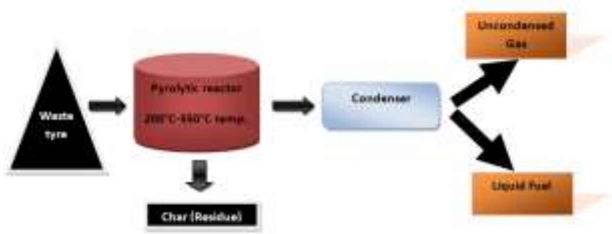


Fig. 1 Schematic diagram of pyrolysis process.

A fixed bed batch type reactor was used for the pyrolysis of tires. The pyrolytic reactor was made by mild steel having radius 120 mm, and height 270 mm. to maintain the inert environment inside the reactor, after feeding the waste tire the reactor was made completely closed. Dry tires cut into small pieces (2-3 cm) and after removal of bead, steel wires and fabrics were fed into the pyrolytic reactor shown in **Fig. 2**. The temperature controller controlled a 2-kW external electric heater, which supplies heat to the reactor. The waste tire pieces inside this reactor were heated by this heat, and they changed their phase from solid to vapor. The reaction was carried out between 250-700°C temperature ranges. The vapors produced by this reaction were sent to water-cooled condenser, and condensate was collected as a crude fuel (WTPO). Some solid residue left out after the process, which can be used as char or carbon black. The flame test was conducted to verify whether WTPO obtained is combustible or not.

Fig. 2 Test set-up for pyrolysis.

2.2 Distillation of WTPO

For separating the lighter and heavier fractions of obtained crude fuel (WTPO), distillation process was performed in a flat bottom round flask having volume 500ml, as shown in **Fig 3**. The heat is supplied for this process by an electric heater of power 2 kW. The temperature controller controlled a 2 kW external electric heater that supplies heat to the flask. Mercury thermometer was used to record the temperature during the process. The Crude WTPO was heated in a temperature range of 180-360°C, belonging to the boiling point of diesel. 74% of the crude WTPO was distilled in the process while 7% escaped out as Pyrogas, and 19% was found as sludge. The time taken to obtain 300ml distilled WTPO was 45 min.

Fig. 3 Test set-up for Distillation of crude WTPO.

2.3 Engine and test procedure

For performance analysis, experiments were carried out in a manually operated, single-cylinder, 4-stroke, water-cooled, compression ignition diesel engine **Fig 4**. The specifications of the engine setup are listed in **Table 1**.

Table 1 Specifications of the diesel engine set-up.

Specification	**Data/Information**
Engine	Manually operated, 4-stroke, single cylinder, compression ignition diesel engine
Cooling system	Water cooled
Compression ratio	18:1
Rated power	7 HP
Rated speed	600 rpm
Bore size	114 mm
Stroke size	140 mm

WTPO was blended with pure diesel at different blending ratio, and the mixture was fed in the diesel engine for the experiment. Rope brake dynamometer was used for generating test in this experiment. Specifications of rope brake dynamometer are listed in **Table 2.** The brake powers of 0, 1.5946, 2.3540, 3.0565, and 3.3033 kW were applied on WTPO of different blending-ratio at a constant speed of the engine 600 rpm. The brake theraml efficiency (η_{bth}), and the brake specific fuel consumption (bsfc) were recorded for the performance analysis of the engine.

Table 2 Specifications of rope brake dynamometer.

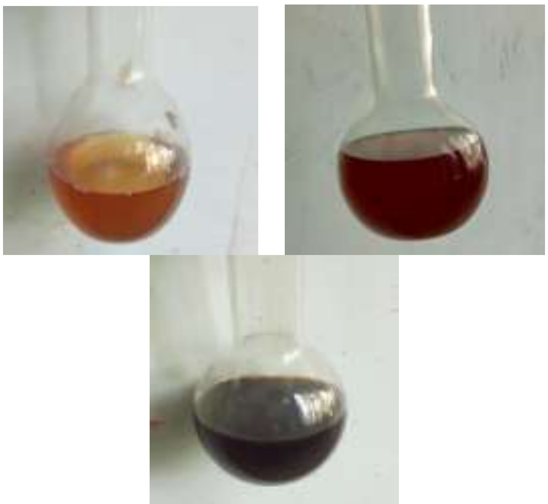
Specification	Data
Diameter of the rope (d)	16 mm
Diameter of break drum (D)	600 mm
Overall radius of brake drum and rope	308 mm

Fig. 4 Diesel engine test set-up.

3. Results & Discussion

3.1 Distillation

Fractional distillation was carried out at three temperature ranges such as 180-220°C, 220-260°C, and 260-360°C. These temperature ranges were chosen based on the quality of distilled WTPO obtained.



(a) (b) (c)

Fig. 5 WTPO obtained in temperature range (a) 180-220°C, (b) 220-260°C, (c) 260-360°C.

Distilled WTPO obtained in 180-220°C temperature range was light orange in color **Fig 5(a)**, in 220-260°C temperature range was dark orange in color **Fig 5(b)**, and in 260-360°C temperature range was brownish orange in color **Fig 5(c)**. It was observed that as the color of the distilled WTPO was darkening the density of the fuel was increasing while the calorific value was decreasing. It was due to change in composition of the distillate based on the boiling point. For the present analysis distilled WTPO in temperature range 180-220°C was selected.

3.2 Fuel properties

Pure diesel Is blended with WTPO at various blending ratio(5%(WTPO5), 10%(WTPO10), 15%(WTPO15), and 20%(WTPO(20)) and properties of the blend such as density and calorific value has been calculated as listed in **Table 2**.

Table 3 Properties of pure diesel, WTPO, and blends.

Fuel	Density(gm/cm^3)	Calorific value(KJ/kg)
Diesel	0.83	44800
WTPO	0.833	42660
WTPO5	0.83015	44693
WTPO10	0.8303	44586
WTPO15	0.83045	44479
WTPO20	0.8306	44372

It can be observed from the **Table 2** that the density of WTPO is higher than the pure diesel, so the density of the blend is increasing with the blend ratio. And the calorific value of the WTPO is slightly lesser than the diesel, so the calorific value of the blend is decreasing with the blend ratio.

3.2 Engine performance

For the performance analysis of diesel engine generating test has been conducted, and brake power of the engine has been calculated using rope brake dynamometer. For this purpose tests were performed at different blend ratios 0%, 5%, 10%, 15% and 20%, at different brake power 0kW or no load, 1.5946kW, 2.3540kW, 3.0565kW and 3.3033kW at constant speed of engine (600 rpm). Results showed that engine performance did not change significantly up to a 20% blend ratio. Irregular engine behavior (i.e., power and unstable speed), worsening of brake power, bsfc, and efficiency of the engine were observed at a higher blending ratio. Extremely irregular behavior of the engine, deterioration in performance, and difficulties in starting the engine were observed over 45% blend ratio.

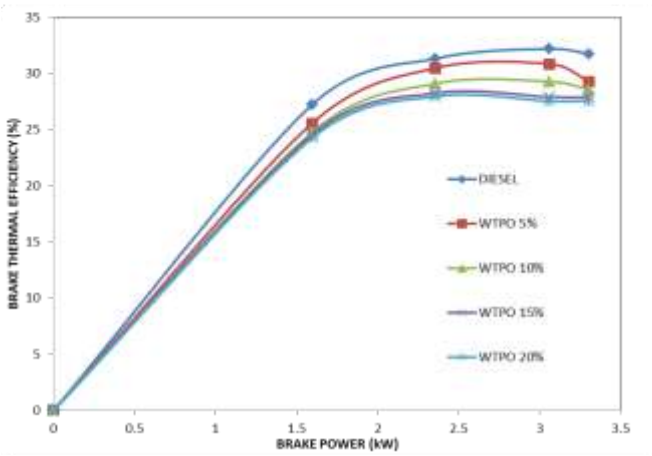


Fig. 6 Variation of brake thermal efficiency (%) with brake power (kW).

Fig 2. Shows the brake thermal efficiency vs. brake power at 600 rpm. Brake thermal efficiency for four different blend ratio was plotted with different brake power. It can be observed that brake thermal efficiency continues to decrease as the blend ratio increases. More decrement in brake thermal efficiency with respect to pure diesel can be seen at higher load conditions, whereas at lower load conditions, the variation in brake thermal efficiency is not more significant.

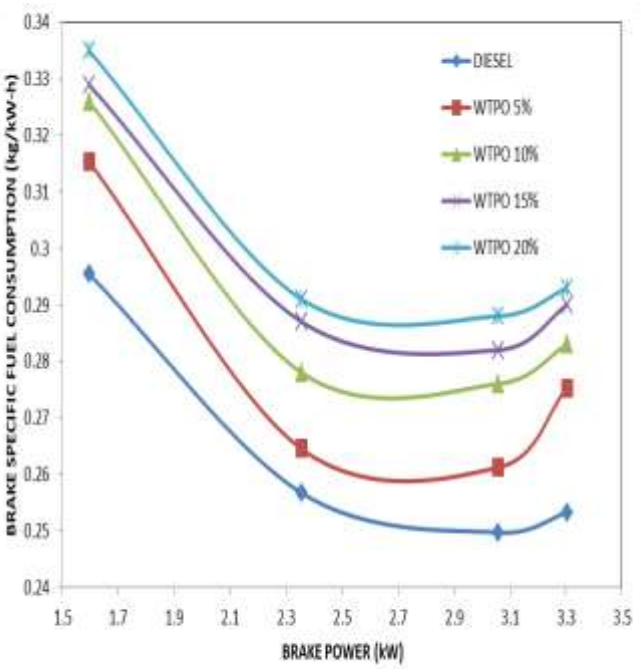


Fig. 7 Variation of brake specific fuel consumption (kg/kW-h) with brake power (kW).

Fig 3. Shows the brake specific fuel consumption (bsfc) vs. brake power at 600 rpm. Brake specific fuel consumption for four different blend ratio was plotted with different brake power. It can be observed that bsfc continues to increase as the blend ratio increases, which means that the performance of the diesel engine is worsening. More increment in bsfc can be observed between 0 to 10% blend ratio.

4. Conclusions

Waste tires were converted into pyrolytic oil in a fixed bed batch type pyrolytic reactor at a temperature range 250-700°C. The following main conclusions have been drawn from the present study:

- Waste tires can be used for producing light liquid fuel as diesel using a pyrolytic process followed by fraction distillation.
- Working temperature and heating rate has a great effect on product yield. 430-550°C temperature range and 24°C/min heating rate found as the optimum working condition for pyrolysis of waste tires. At this optimum working condition, liquid, solid, and gas yield were about 43, 52, and 5 wt%, respectively. At other than this condition yielding of gas product increases and of liquid decreases.
- The crude WTPO obtained was a viscous, high density, sticky in nature, and black in color. This is a flammable fuel as it passes the flame test. This fuel cannot be used directly in diesel engines as it contains a high amount of sulphur content and suspended particles.
- The fractional distillation process was performed for separating lighter and heavier fractions of WTPO at the temperature range belonging to the boiling point of the diesel(180-360°C). but the temperature range of 180-220°C was found the optimum temperature range for the distillation process as the WTPO obtained in this range the best fuel having light orange color and highest calorific value 42660 kJ/kg and density 0.833 gm/cm^3. As the temperature range increases, the color of the fuel became dark orange and then brownish-black as the quality of the fuel deteriorated.
- The generating test on diesel engine was performed with WTPO and diesel blend at different blending ratios. As the blending ratio increases from 5% to 20%, the engine performance deteriorates, i.e., brake thermal efficiency decreases and brake specific fuel consumption increases with respect to pure diesel. As the blending ratio further increased, the diesel could not be started.
- The process has a great environmental impact. Solid waste management is possible as the waste is converted into an energy source.

Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

Acknowledgments

The first author thankfully acknowledges the guidance and consistent support by Dr. Apurba Layek. The first author further records his thankfulness for financial support by the Ministry of Human Resource and Development (MHRD).

References

[1] Rashad, A. M., 2016. *A comprehensive overview about recycling rubber as fine aggregate replacement in traditional cementitious materials. International Journal of Sustainable Built Environment,* 5(1), pp.46-82.

[2] Sharma, V. K., Fortuna, F.A.B.I.O., Mincarini, M.A.R.C.E.L.L.O., Berillo, M. and Cornacchia, G.I.A.C.I.N.T.O., 2000. *Disposal of waste tyres for energy recovery and safe environment. Applied Energy*, 65(1-4), pp.381-394.

[3] de Marco Rodriguez, I., Laresgoiti, M. F., Cabrero, M. A., Torres, A., Chomon, M. J. and Caballero, B., 2001. *Pyrolysis of scrap tyres. Fuel Processing Technology*, 72(1), pp.9-22.

[4] Dıez, C., Martınez, O., Calvo, L. F., Cara, J. and Morán, A., 2004. *Pyrolysis of tyres. Influence of the final temperature of the process on emissions and the calorific value of the products recovered. Waste Management*, 24(5), pp.463-469

[5] Williams, P. T., 2013. *Pyrolysis of waste tyres: a review. Waste Management,* 33(8), pp.1714-1728.

[6] Alsaleh, A. and Sattler, M. L., 2014. *Waste tire pyrolysis: Influential parameters and product properties. Current Sustainable/Renewable Energy Reports,* 1(4), pp.129-135.

[7] Kumaravel, S. T., Murugesan, A. and Kumaravel, A., 2016. *Tyre pyrolysis oil as an alternative fuel for diesel engines–A review. Renewable and Sustainable Energy Reviews*, 60, pp.1678-1685.

[8] S. Murugan, *performance emission and combustion studies of a DI diesel engine using distilled tyre pyrolysis oil-diesel blend*

[9] Martínez, J. D., Rodríguez-Fernández, J., Sánchez-Valdepeñas, J., Murillo, R. and Garcia, T., 2014. *Performance and emissions of an automotive diesel engine using a tire pyrolysis liquid blend. Fuel,* 115, pp.490-499.

[10] Frigo, S., Seggiani, M., Puccini, M. and Vitolo, S., 2014. *Liquid fuel production from waste tyre pyrolysis and its utilisation in a Diesel engine. Fuel,* 116, pp.399-408.

[11] Seljak, T., Oprešnik, S. R. and Katrašnik, T., 2015. *Combustion characteristics of tire pyrolysis oil in turbo charged compression ignition engine. Fuel*, 150, pp.226-235.

[12] Hürdoğan, E., Ozalp, C., Kara, O. and Ozcanli, M., 2017. *Experimental investigation on performance and emission characteristics of waste tire pyrolysis oil–diesel blends in a diesel engine. International Journal of Hydrogen Energy*, 42(36), pp.23373-23378.

[13] Water, C. and Energy, H., *About Chintan Environmental Research and Action Group*.

[14] Murugan, S., Ramaswamy, M.C. and Nagarajan, G., 2008. *The use of tyre pyrolysis oil in diesel engines. Waste Management, 28*(12), pp.2743-2749.

[15] Sharma, A. and Murugan, S., 2015. *Potential for using a tyre pyrolysis oil-biodiesel blend in a diesel engine at different compression ratios. Energy Conversion and Management, 93*, pp.289-297.