Effect of camphor oil on a plastic pyrolysis oil fueled DI diesel engine

G Kasiraman*, Ankit Manoharan, M Chethan Sai

Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur - 603203, Chengalpattu District, Tamil Nadu, India

*Email:kasiramg1@srmist.edu.in

Abstract: Plastics, as we know have become almost impossible to dispose in today's times and their use is consistently on the rise. Because of its high heating value and availability, plastic waste can be used as a source of energy. Pyrolysis process will turn this plastic into oil, which can then be employed as fuel in IC engines to generate heat and power. The use of neat plastic pyrolysis oil in a DI engine will result in low BTE and more incomplete combustion. This is due to its high viscosity. This issue can be solved by blending the PPO with camphor oil. The properties of the plastic pyrolysis oil (PPO) were examined and it was found to be similar to diesel. The two fuels were run separately on a 4 stroke, direct injection, single cylinder, diesel engine with a rated power of 5.2 kW at 1500 rpm and a CR of 17.5. The PPO was then blended with camphor oil at 5%, 10%, and 15% by volume and the combustion, emission and performance characteristics studied. It was found that the PPO85C15 blend had the highest brake thermal efficiency and the lowest HC emissions.

1. Introduction

Nowadays, the consumption of fossil fuels has increased drastically. A large percentage of vehicles use internal combustion engines, which use fuels like diesel and petrol. The consumption of fossil fuels is increasing year by year due to the heavy utilization of vehicles. This leads to an energy scarcity problem. Many researchers from around the world are trying to find alternative sources of energy. Diesel engines are heavily used in industrial and transport sectors due to their good thermal efficiency and minimum fuel consumption. The drawback of using a diesel engine is that they have higher emissions compared to petrol engines or SI engines. Researchers are trying to find alternative fuel without compromising on its performance and emissions. In the recent years, researchers have started focusing on using the oil produced from plastic waste in diesel engine due to its abundance and its energy content.

Ioannis Kalargaris et al. [1] did a study on using WPO in a marine engine and how it affects the engine. It was found out that there was a 3 – 4% decrease in BTE when WPO was used as compared to that of diesel. All emission parameters were higher than diesel. The research findings indicate that for extended use, a 60% - 70% blend of PPO running at about 85% load appears to bring about the best performance and emission characteristics.

R.K Singh Biswajit et al. [2] did a research on using plastic oil blended with diesel. The BTE is higher for the 20% blend at 31.61%. The same was the case of specific fuel consumption. The heat release rate for the 50% PPO blend was found to have a higher HRR with 149.18J/°CA.
A comparative study of the effect of PPO and TPO on a diesel engine was done by C. Wongkhorsub and N. Chindaprasert [3] in 2013. The engine that they used had a compression ratio of 23.5. The plastic pyrolysis oil had a slightly higher calorific value (2.973 MJ/kg more than TPO) and flash point (32° higher than TPO) whereas the tire pyrolysis oil had a higher density (0.1093 g/cc higher) and viscosity (0.2 cP). They found that more waste is produced during the synthesis of PPO than TPO. The TPO had a lower load production than diesel but higher than plastic pyrolysis oil. The presence of aromatic and complex compounds in the tire pyrolysis oil cause it to have a higher efficiency than plastic pyrolysis oil.

M. Mani, G. et al.[4] studied how a CI engine would be affected when diesel and plastic oil blends was used in an engine. It was found that WPO has a higher maximum pressure than diesel. The rate of heat release of WPO is higher than that of diesel. Owing to the higher heat release and peak temperature associated with higher WPO percentages, NOx levels rise. The smoke levels also increased by 35% - 40%. Hariram Venkatasen et al.[5] did an experimental study on a DI CI engine by using diesel and plastic oil blends in the engine. They noticed that the peak cylinder pressure increased as the percentage of plastic oil increased. At maximum load conditions, the BTE for diesel is 30.27%, for PO15% it is 26.2% and for PO30% it is 28.4%.

The effect of diesel and camphor oil blends on a direct injection diesel engine was studied by S. M. Sivagami et al.[6]. The experiment showed that the BTE of the engine increases with progressive introduction of camphor oil to the blend. The carbon dioxide emissions are also lower for the blends at higher loads. While the NOx emissions are higher for the camphor oil blends, the CO emissions is shown to reduce as the percentage of camphor oil in the blend increased.

Cashew nut oil (CSNO) was blended with camphor oil and was tested in a DI CI engine by G. Kasiraman et al.[7]. The inclusion of camphor oil decreases the energy demand due to easier blending and smoother burning. The volumetric efficiency of the engine when the camphor blend was used was 3.1% higher than when neat cashew nut oil was used. It is only 1.8% lower than that of diesel. It is observed that increasing the camphor oil percentage in the blends increased the peak heat release. The CO2 emissions were found to be higher for the camphor oil blends. The 30% camphor oil blend has the lowest CO emissions and addition of camphor oil reduces the HC emissions. The camphor oil blend also produces less smoke than the neat cashew nut oil.

Viswanath K. Kaimal et al.[8] did an experiment on plastic oil in a CI DI engine. They found that the thermal efficiency is 27.5%, which is lower than that of diesel, which is 31.4%. They also noted that the specific energy consumption is lower for plastic oil at rated power. This is due to its high heating value. Plastic oil has a higher cylinder pressure of 71 bar when compared to diesel, which is 67 bar. The heat release rate is also higher for plastic oil of 1132J, whereas for diesel, it is 990J. P. Senthil Kumar et al.[9] did an experiment on a DI CI engine by using WPO and JME blend and running it at a constant speed and varying the load. They conducted the experiment on four different fuels, namely diesel, WPO, PJ20 and PJ10. The BTE for diesel at peak load conditions is 24.96% and for plastic oil is 22.61%, for PJ10 it is 22.83% and for PJ20 it is 24.35%. The engine consumes less diesel (0.35kg/kwh) compared to other fuels at peak load conditions. The peak cylinder pressure, they noticed, decreased by adding more amount of JME. HRR is higher for plastic oil compare to other fuels. Whereas for the WPO-JME blends, it reduced. They noticed that the cylinder temperature is reduced due to the reduction in ignition delay. Therefore, it led to a reduction in HRR for the WPO-JME blends. They noticed reduction in unburned hydrocarbons emitted in the case of WPO-JME blends compared to neat plastic oil. They noticed that the WPO-JME blends emitted more NOx as the percentage of JME increased. The CO emission is lower for blends compared to diesel at peak load. JME contains higher amount of oxygen which is helpful for better combustion. The addition of JME to WPO reduces the smoke opacity.

2. Experimental Setup
The specifications of the engine that was used for the experiment is shown below in Table 1. In this experimental setup, the fuel is directly injected into the cylinder where the combustion occurs. The engine cylinder is coupled to a piezo electric transducer to accurately measure the pressure inside the cylinder. A crank angle sensor with a resolution of 1° and a speed of 5500 RPM with a TDC pulse was connected to
measure the crank angles. In order to apply the load, an engine is equipped with an eddy current dynamometer, which measured the engine power output at different loads (0%, 25%, 50%, 75% and 100%).

### Table 1. Specification of test engine

| Make and Model            | Kirloskar TV1 engine |
|---------------------------|----------------------|
| No of cylinders           | 1                    |
| No of strokes             | 4                    |
| Power                     | 5.2 kW               |
| Bore length               | 87.5 mm              |
| Stroke length             | 110 mm               |
| Speed                     | 1500 rpm             |
| Cooling system            | Water cooled         |
| Dynamometer               | Eddy current type    |

### Table 2. Properties of fuel

| Fuel Property     | Diesel | PPO  | CMPO |
|-------------------|--------|------|------|
| Density (g/cm³) at 15°C | 0.830  | 0.8208| 0.8942|
| Kinematic Viscosity (cSt) at 40°C | 3.11   | 2.98  | 1.9   |
| Gross Calorific Value (MJ/kg) | 42.5   | 38.18 | 38.20 |
| Cetane Number      | 52     | 35   | 5    |

The data acquisition device, along with the crank angle sensor measures and records all the pressure crank angle data. With the assistance of appropriate hardware, a specialized program was integrated with the engine, allowing the transducers and sensors to provide the necessary data to the software so that the performance and combustion characteristics can be calculated. To measure the emission (carbon monoxide, hydrocarbon, carbon dioxide, oxygen, nitrogen monoxide), AVL five gas analyzer (AVLDI GAS444N) was used. And to measure the smoke levels and opacity, AVL 437C smoke meter was used.

### 2.1 Test Procedure

The DI diesel engine was run on diesel for some time to warm it up before the experiment was performed. The test fuels that were used were Diesel, neat PPO and 5%, 10% and 15% camphor oil blended with PPO. The engine was maintained at a constant speed of 1500 rpm and the load was varied. For each load condition, the SFC, power output, emissions and the pressure-crank angle data were obtained. The BTE, BSFC and volumetric efficiency were derived for the different loads using the integrated software. The rate of heat release, and peak pressure were derived from the pressure-crank angle data.
3. Result and discussion

3.1 Performance Characteristics

Brake thermal efficiency (BTE) is the ratio between the output power to the input power of the fuel. Figure 2 shows the BTE for different blends at different loads. When blending with camphor oil, the results improved. For PPO95C5, PPO90C10 and PPO85C15, the brake thermal efficiencies are 32.46%, 32.56% and 33.31% respectively. Camphor oil has good combustion properties; its viscosity is also low compared to PPO. When we blended camphor oil, the viscosity of the blend is improved and this increases the vaporization of fuel.

Brake Specific Fuel Consumption shows how much fuel the engine consumes, to the power it produces. It helps in explaining the engine efficiency. The variation of BSFC with load is shown in Figure 3. PPO100 consumes more fuel for the same output as remaining fuels. It consumes 0.32 kg/kwh at full load condition where thermal efficiency is more. Whereas for D100 it is 0.26 kg/kwh. When camphor oil was added to the PPO, the BSFC is decreased when compared to PPO100. The low viscosity of the camphor oil improves the atomization of fuel in the chamber which increases the air-fuel mixture leading to less fuel utilization.
3.2 Combustion Characteristics:

Figure 4 shows data on the heat release rate of fuels at different crank angles. For plastic pyrolysis oil, the maximum heat release rate is 57.97J/deg. When blended with camphor oil at 5%, 10% and 15%, it is 58.39J/deg, 61.39J/deg and 63.13J/deg respectively. For PPO blends, the maximum heat release takes place mainly in the rapid combustion phase. The heat release rate is highest in the PPO85C15 blend. This is due to the higher percentage of camphor oil in the blend. The camphor oil acts as the ignition centre and ignites all the fuel around it thus increasing the heat release rate.

Figure 5 shows the volumetric efficiency for different blends at different load conditions. The volumetric efficiency for neat PPO is 82.92% at maximum load conditions. For the PPO85C15 blend, it is 83.03%. This is closer to that of diesel, which is 83.68%. In the case of neat PPO and the camphor oil blends, the combustion continues into the exhaust stroke. So, less amount of fresh air is taken in during the intake stroke. Therefore, the volumetric efficiency is lower.

Figure 6 shows the variation in peak pressure at varying loads. The peak pressure increases as the load increases. Plastic pyrolysis oil has a peak pressure of 71.11 bar compare to diesel, which is 70.77 bar. When
the PPO was blended with camphor oil, which has a lower viscosity, the peak cylinder pressure decreases. The peak pressure is high for plastic pyrolysis oil and its blends with camphor oil because of their higher ignition delay and viscosity, making use of more fuel to take part in premixed combustion phase.

![Figure 4. Heat Release Rate Vs Crank Angle](image)

![Figure 5. Volumetric Efficiency Vs Load](image)
3.3 Emission Characteristics:
Figure 9 shows the amount of carbon monoxide emitted at different load conditions. This toxic gas is released due to the lack of oxygen, improper air fuel mixture and incomplete combustion inside combustion chamber. At low load conditions the CO emission is more due to lower temperature inside the chamber. As load increased the temperature inside the chamber increases which improves reaction. At full load condition more amount of fuel is injected which leads oxygen scarcity to all fuel to burn properly. For diesel at full load condition CO emission is 0.187% and for neat PPO it is 0.26%. For the PPO95C5, PPO90C10 and PPO85C15 blends, the values are 0.24%, 0.23% and 0.23% respectively.

Unburned hydrocarbons are emitted mainly due to improper combustion of air fuel mixture. Viscosity also plays a major role in HC emission. High viscosity leads to formation of bigger fuel droplets in the chamber which causes improper combustion. Figure 7 shows the HC emissions with varying load. The HC emissions increases with an increase in load. For diesel the HC emission is 79 ppm and for the PPO100 the value is 85ppm, at full load. For PPO95C5 it is 82ppm and for PPO90C10 it is 81ppm. The PPO85C15 blend shows the least emission at maximum load with 77 ppm.

Figure 10 shows the variation emission of carbon-dioxide for diesel, plastic oil and plastic oil blends with camphor oil. There is increase in emission of carbon-dioxide for all the blends with vary load condition from no load conditions to full load conditions. Diesel emitted 10.9% CO2 under full load. For neat PPO it was 11.7%. For the 5%, 10% and 15% camphor oil blends, the CO2 emissions were 12.5%, 11.5% and 11.9%. The level of carbon dioxide in the exhaust gas indicates how much combustion occurs, so higher the CO2 levels, more the combustion.

Nitrogen oxides are formed when oxygen and nitrogen react at high temperature. Figure 8 shows the variation of NOx emissions with varying load. The NOx increases as the load increases. It is highly temperature dependent. When blending camphor oil with plastic oil, the NOx emission increased. The NO emissions for diesel at full load is 1803 ppm and the same is 2099 for neat PPO. For PPO95C5, PPO90C10 and PPO85C15 the value is 1972 ppm, 2056 ppm and 2184 ppm respectively, at maximum load. When blended with camphor oil, the combustion improves. Therefore, the peak temperature and heat release rate increases. This will result in a higher NO emission.

The smoke opacity of fuels increases with increasing engine load. This is shown in Figure 11. As the engine load increases, the air fuel ratio decreases with increasing fuel injection. This results in higher smoke. The long chain aromatic compounds in the PPO cause higher amounts of smoke due to poorer combustion taking place. At peak load condition the smoke opacity for diesel and PPO are 63.1% and 80.9% respectively.
However, when blended with camphor oil at 5%, 10% and 15% the smoke levels were reduced to 78.2%, 76.3% and 78.5% respectively. This is due to better combustion and better ignition of the blends.
4. Conclusion

The utilization of plastic pyrolysis oil as fuel for diesel engine showed a positive result for use as an alternative fuel. The performance, combustion and emission characteristics of PPO was improved by adding camphor oil, which has good combustion properties. The results were improved compared to PPO100. The camphor oil is blended with PPO in three different ratios, PPO95C5, PPO90C10 and PPO85C15. The addition of camphor oil to plastic pyrolysis oil up to 15% improved the brake thermal efficiency compared to diesel. It improved the fuel properties of plastic pyrolysis oil. Brake specific fuel consumption is minimum for PPO85C15 compare to PPO100. It shows that it consumes less fuel to produce the power compared to PPO100. It shows good fuel characteristics when blending with camphor oil. High heat release rate was shown in PPO85C15 compared to PPO100. This is due to the addition of camphor oil which acts as the ignition center and ignites all the fuel around it. Unburned hydrocarbon emission is reduced for PPO85C15 compared to the other fuels tested, owing to improved combustion. Nitrogen monoxide emission is higher for PPO85C15 due to high HRR and in-cylinder temperature allowing nitrogen to react with oxygen to produce more amount of nitrogen. Smoke opacity increases for all the fuels with increasing load. PPO releases high amount of smoke opacity due to improper combustion and diesel is the least.
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