Diesel Engine Performance Operating with Tire Derived Fuel

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Abstract. Fossil fuel is non-renewable energy. This type of energy sources are widely used in many critical areas such as industrial application and vehicle application. Realizing this fact, many researches are conducted to produce alternative energy sources to reduce the dependence to fossil fuel for energy generation. As for example, fuels that produced from natural sources such as palm, rapeseed and jathropa are commonly used as alternative fuel especially for transportation purpose. Apart from natural sources, waste source such as used tires also can be utilized to produce alternative fuel. In this paper, the engine performance of diesel engine operating with unblended tire derived fuel (TDF) are analyzed and compared to diesel fuel. The experiment is conducted using a single cylinder, direct injection diesel engine. The engine operates at variable engine speed while constant load exerted to the engine. The performance parameters that are analyzed in the experiment includes engine power, engine torque, combustion pressure and exhaust gas temperature. Results from the experiment shows that diesel engine can operate with unblended TDF. However, TDF is not suitable for high engine speed applications. Furthermore, TDF produce lower performance output compared to diesel fuel.

1 Introduction

Diesel engines are dominant source for power generation in wide applications such as automobiles, marines, agriculture and others. Diesel engines are preferred in such application especially in heavy duty application due to its advantages over gasoline such as higher torque, high thermal efficiency and high drivability (McAllister et al., 2011). Nowadays, diesel engine technologies have advanced to produce more efficient, higher output and less emission diesel engine. Common rail injection system, force induction system and direct injection system are examples of modern diesel technology that available today.

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The numbers of motorized vehicles around the globe are increased including Malaysia. According to statistics by Malaysia Automotive Association (2015), 666, 465 units of vehicle are sold in 2014 compared to 655, 793 units of vehicles in 2013. Additionally, the increasing numbers of vehicles also cause the increasing amount of scrap tires. According to Chong (2006), Malaysia generates about 150, 000 tons of scrap tires every year. With the increasing number of vehicles in Malaysia, this number is expected to increase.

One of the initiatives that can be done to overcome the waste tire problem is by recycling it into useable product through alternative technologies (Banar et al., 2012). Waste tires can undergo thermal degradation process with absence of oxygen which knows as pyrolysis process to convert the scrap tires into liquid fuel knows ad tire derived fuel (TDF). Studies that conducted by Panda (2010) concluded that pyrolysis process can be done either with presence of catalyst or not where catalyst can increase the yield rate of TDF. The temperature that used in the process ranged from 350 °C to 500 °C.

This fuel is claimed by several researchers to have high calorific value (Fernández et al., 2012), (Abdul-Raouf et al., 2010), (Bajus and Olahová, 2011). This high calorific value makes TDF possibly can be used as alternative fuel in diesel engine. However, TDF has high content of sulphur since the scrap tires undergo vulcanization process to improve the strength of the tires (Al-Lal et al., 2015). High sulphur contents will cause high amount of particulate matters emitted to the environment where it can be subject to other reactions contributing to the creation of the London type smog and acid rain (Merkisz et al., 2002).

Doğan (2012) experimenting on the effect of TDF on engine performance and exhaust emission in a diesel engine. Six samples of TDF blended with diesel fuel at several ratios together with neat diesel are tested. Tests are performed using a single cylinder, direct injection diesel engine. From the experiment, it is concluded that diesel engine is able to run with maximum 90% of TDF blend ratio in diesel fuel. Usage of 100% TDF in diesel engine will cause malfunction at higher engine speed.

İlkılıç and Aydın (2011) studied the effect of TDF running in diesel engine at several blend ratio. Seven different blend ratio of TDF and diesel fuel together with 100% unblended TDF and neat diesel are tested. From the results obtained, it is concluded that torque and power output decreased when TDF blend ratio in diesel fuel is increased. In this study, diesel engine is able to run with 100% unblended diesel. However, the power and torque output is the lowest when 100% unblended TDF is used compared to the other test fuels.

Martínez et al.(2014) studied the potential of TDF to be used in light duty diesel engine under transient condition. In the study, 5 vol.% of TDF is blended with commercial diesel fuel and tested in a light-duty diesel Euro 4 engine. From the study, it is concluded that the TDF possibly can be used in diesel engine without constructive modifications. However, the emissions such as smoke opacity and particulate emissions of blended TDF-diesel fuel is higher compared to pure diesel.

2 Experimental Setup and Details

The schematic diagram for experimental setup is shown in Figure 1. A direct-injection, single cylinder water cooled diesel engine (YANMAR TF 120M) employed in this research. The technical data for the engine used is shown in Table 1. During experiment, the engine was tested without any modification.

The engine is coupled using NBK coupling to a positive displacement gear pump (Hydrome HGP-3F-23) which functions as hydraulic dynamometer. An airbox is fitted to the engine intake manifold for airflow measurement. The data are taken using data acquisition system (TFX Engineering) which consists of in-cylinder pressure sensor and crank angle sensor. The exhaust temperature, ambient temperature and intake temperature are measured using K type thermocouples. The thermocouples are placed at exhaust manifold, intake manifold and air measurement unit.

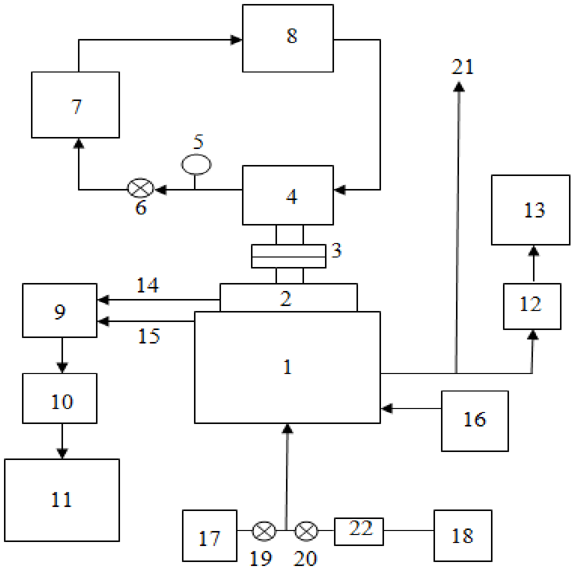

Fig. 1. Experimental Setup.

The engine speed parameter is set at five different speeds which are 1200 rpm, 1500 rpm, 1800 rpm, 2100 rpm and 2400 rpm and constant load at 800 psi pressure is exerted to the engine. The engine is run at desired engine speed at the beginning of each setup. Then, the load is exerted to the engine after stable operating condition is achieved. The data is taken after the load exerted where the speed measurement remain stable for at least one minute. The engine is run using conventional diesel fuel at the beginning to obtain base data for comparison.

For TDF data measurement, the engine is run with diesel fuel for beginning. After five minutes running on diesel fuel, the valve supplying the diesel fuel to the engine is closed and after a while, the valve for supplying TDF into the engine is opened. The engine is let running for at least five minute before the data is taken to ensure only TDF is injected into the combustion chamber. The data measured are engine power, torque, combustion pressure and exhaust gas temperature.

Table 1. Engine Specification.

	Specification
Engine type	YANMAR TF120M
Number of cylinder	1
Bore x stroke	92 x 96 mm
Displacement	0.638 L
Compression ratio	17.7
Injection timing	17° BTDC
Continuous output	10.5 HP at 2400 rpm

The fuels undergo chemical testing to determine the chemical properties for each fuel. The chemical properties for diesel and TDF used in the experiment are shown in Table 2.

Table 2. Chemical Properties of TDF and diesel fuel.

Properties		Diesel	TDF
Density	[g/cm^3]	0.8416	0.923
Kinematic Viscocity@ 40 ^{0}C	[cst]	3.05	5.1
Flash Point	[^{0}C]	84	44
Gross calorific Value	[MJ/kg]	42.4915	38

3 Results and Discussions

Figure 2 shows the engine power measures at various engine speeds while constant load exerted to the engine. From the figure, it can be observed that TDF gives lower power output compared to diesel fuel by 13.49 % in average. This condition may cause by the lower gross calorific value of TDF compared to diesel fuel as shown in Table 2. Fuel that has lower gross calorific value will produce lower energy level when combusted in the combustion chamber.

Figure 3 shows the torque output when diesel and TDF is used in diesel engine. From the figure, it is shown that when TDF is used, the fuel will produce lower torque compared to diesel fuel. This condition may be related to the amount of energy that produced when TDF is combusted. The combustion of this fuel produce lower amount of energy due to its lower gross calorific value compared to diesel fuel. This factor will cause lower combustion pressure that will lead to lower torque when TDF is combusted.

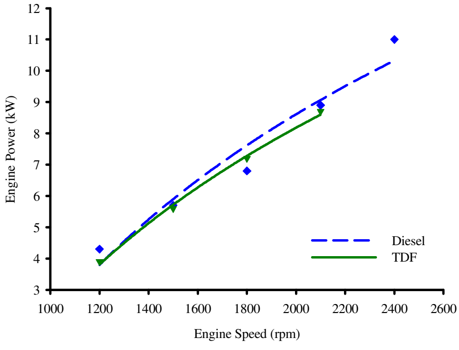

Fig. 2. Graph of Power Output at Various Engine Speed

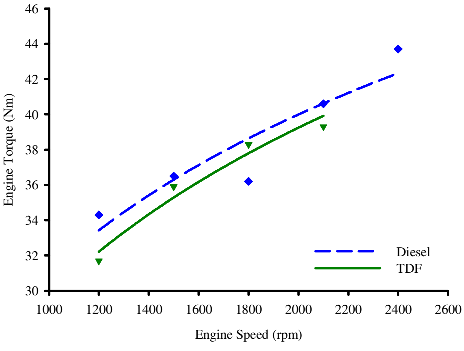

Fig. 3. Experimental Setup. Graph of Torque Output at Various Engine Speed

Figure 4, Figure 5 and Figure 6 shows the combustion pressures and ignition delay at three different speed regions which are 1200 rpm, 1800 rpm and 2100 rpm. This engine speed represents the condition at low engine speed region, moderate engine speed region and high engine speed region. Referring to the Figure 4, it can be observed that TDF has longer ignition delay compared to diesel fuel at lower engine speed region where the ignition of TDF begins at 1° aTDC. This condition can be related to lower cetane number of TDF compared to diesel fuel as stated by Bhatt and Patel (2012). Lower cetane number of TDF will results to longer ignition delay.

Furthermore, longer ignition delay of TDF will contribute to rough and un-smooth diesel engine operation. Longer ignition delay will cause more fuel present in the combustion chamber during the period between the times after the fuel injected inside the combustion chamber until the combustion begins. Therefore, when the combustion begins, a rapid combustion phase will take place at the beginning, where rapid and higher pressure rise will occur as a result of large amount of fuel inside the combustion chamber. This condition will cause audibly knocking sound, sometimes referred as "diesel knocks" (Baranescu and Challen, 1999) thus resulting rougher diesel engine operation. This diesel knocks can be heard clearly during the experiment especially at low engine speed region when TDF is used.

From Figure 4, it also can be observed that TDF has higher combustion pressure which is 80.2 bar compared to diesel fuel which is 76.6 bar. This condition can be related to longer ignition delay of TDF compared to diesel fuel. As mentioned earlier, longer ignition delay cause more fuel exist in the combustion chamber during the ignition delay period. Hence, when the combustion starts a rapid and higher pressure rise will occur hence producing higher peak pressure for TDF compared to diesel fuel.

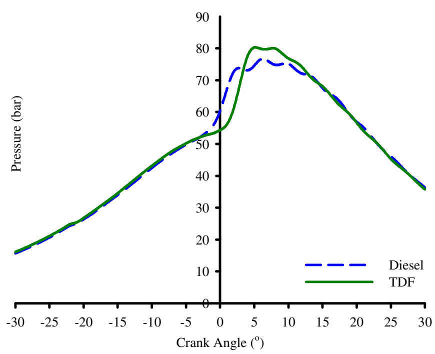

Fig. 4. Graph of Combustion Pressure vs Crank Angle at 1200RPM

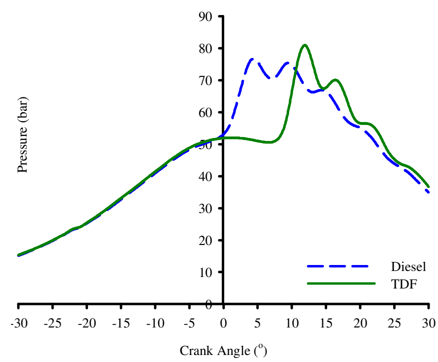

Fig. 5. Graph of Combustion Pressure vs Crank Angle at 1800RPM

Figure 5 represents the combustion pressure at moderate engine speed region which at 1800 rpm. From the figure, it can be observed that the ignition delay of TDF is longer compared to diesel fuel due to its lower cetane number. Furthermore, compared to low speed region, it can be seen that TDF will produce longer ignition delay when the engine speed is increase. For the peak pressure, TDF produce higher peak pressure compared to diesel fuel because of its longer ignition delay.

Figure 6 shows the combustion pressure at high engine speed region which is 2100 rpm. From the figure, it is shown that the ignition delay of TDF is longer compared to diesel fuel. This condition also can be related to the density of the fuels alongside with cetane number. The density of TDF is higher compared to diesel fuel. Higher density fuel cause higher fuel flow resistance in the injection system thus will cause poor fuel atomization (Tan et al., 2013). Poor fuel atomization will cause longer ignition delay of the fuel. For the peak pressure, it can be seen that TDF produce comparable peak pressure compared to diesel fuel. However, compared to moderate engine speed region, the peak pressure of TDF is decrease. This is because the combustion of TDF starts when the compression pressure starts to decrease as the piston began to move downward. This condition is caused by the very long ignition delay of TDF. Referring to Figure 6, the pressure curve decreases from 1° crank angle until 8° crank angle before the pressure curve rapidly increase as the combustion starts. Combustion that occurs at this crank angle will cause poor engine performance.

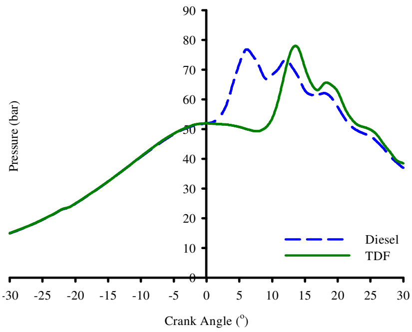

Fig. 6. Graph of Combustion Pressure vs Crank Angle at 2100RPM

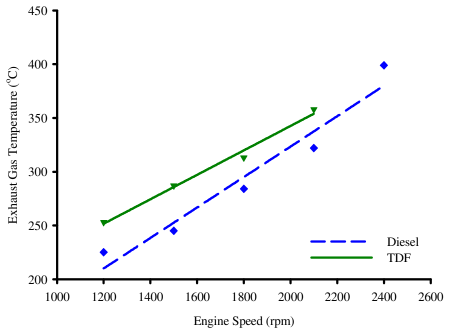

Fig. 7. Graph of Exhaust Gas Temperature at Various Engine Speed

Figure 7 shows the exhaust gas temperature of the tested fuels. From the figure, it is shown that the TDF produce higher exhaust gas temperature compared to diesel fuel. This condition occurs because of longer ignition delay of TDF compared to diesel fuel as shown in Figure 4, Figure 5 and Figure 6. Longer ignition delay cause more fuel exist in the combustion chamber during ignition delay period, causing a rapid, higher rate of heat release when the combustion starts. It is also can be observed form Figure 7 that the exhaust gas temperature increases when the engine speed is increase. This is because when the engine speed increase, more fuel injected inside the combustion chamber thus producing higher exhaust gas temperature.

During TDF usage, when the engine speed is increased until exceeding 2200 rpm, the engine starts to have unstable operation followed by backfire that occurs at the exhaust manifold as shown in Figure 8. This is caused by the lower cetane number of TDF. As mentioned earlier, lower cetane number will cause longer ignition delay. This means the time region starting from the fuel injected inside the combustion chamber until the ignition starts, becomes longer in term of crank angle. As the engine speed increase through low speed region, medium speed region and high speed region, the ignition delay obviously becomes longer. At the high speed region, when the exhaust valve starts to open, some of the unburned fuel enters the exhaust manifold. The high temperature of exhaust manifold will cause the fuel entering the combustion chamber combusted. This condition will cause a backfire observed at the exhaust manifold together with explosion sound when TDF is used. This phenomenon indicates that TDF is not suitable for high speed application since it will cause bad performance and worse emission level. Same findings also stated by Doğan et al. (2012) where it is stated that diesel engine will malfunction at high engine speed for pure, unblended TDF usage.

Fig. 8. Backfire Phenomenon.

4 Conclusion

In this study, engine performance of a single cylinder diesel engine is investigated at five different engine speeds with constant load exerted to it. The fuel that used is TDF where the performance output when TDF is used is compared to diesel fuel. From the results obtained, several conclusions are made:

1. Diesel engine can operate with 100% unblended TDF. TDF produce highest peak pressure and longer ignition delay compared to diesel fuel.
2. TDF is not suitable for high engine speed usage as it cause backfire.
3. TDF produce lower performance output compared to diesel fuel.

References

1. Abdul-Raouf, M. E., Maysour, N. E., Abdul-Azim, A.-A. A. & Amin, M. S., Energ. Convers. Manage., **51**, 1304–1310 (2010).
2. Ahmad, A., *Market Review for 2014 and Outlook for 2015*. (Malaysian Automotive Association, 2015).
3. Al-Lal, A.-M., Bolonio, D., Llamas, A., Lapuerta, M. & Canoira, L., Fuel, **150**, 208–216 (2015).
4. Bajus, M. & Olahová, N., Thermal Conversion of Scrap Tyres. Petrol. Coal, **53**, 98-105 (2011).
5. Banar, M., Akyıldız, V., Özkan, A., Çokaygil, Z. & Onay, Ö. Energ. Convers. Manage., **62**, 22-30 (2012).
6. Baranescu, R. & Challen, B. J. *Diesel Engine Reference Book* (1999).
7. Bhatt, M. P. & Patel, D. P., Int. J. Adv. Eng. Res. Stud., **1**, 61-65 (2012).
8. Chong, T. L., *Waste to Wealth: How it works in Malaysia. IMPAK.* (Department of Environment, Ministry of Natural Resources and Environment, 2006).
9. Doğan, O., Çelik, M. B. & Özdalyan, B., Fuel, **95**, 340-346 (2012).
10. Fernández, A. M., Barriocanal, C. & Alvarez, R., Pyrolysis of a waste from the grinding of scrap tyres. J. Hazard. Mater., **203-204**, 236-243 (2012).
11. İlkılıç, C. & Aydın, H., Fuel Process. Technol., **92**, 1129–1135 (2011).
12. Martínez, J. D., Ramos, Á., Armas, O., Murillo, R. & García, T., Appl. Energ., **130**, 437-446 (2014).
13. Mcallister, S., Chen, J.-Y. & Fernandez-Pello, A. C., *Diesel Engines. Fundamentals of Combustion Processes*. (Springer, 2011).
14. Merkisz, J., Kozak, M., Bielaczyc, P. & Szczotka, A., J. KONES Intern. Combust. Eng., **3-4** (2002).
15. Panda, A. K., Singh, R. K. & Mishra, D. K., Thermolysis of waste plastics to liquid fuel; A suitable method for plastic waste management and manufacture of value added products—A world prospective. Renew. Sust. Energ. Rev., **14**, 233–248 (2010).
16. Tan, E. S., Idris, M. A., Roseli, A. & Anwar, M., *Biodiesel for Gas Turbine Application — An Atomization Characteristics Study. In: NG, H. K. (ed.) Advances in Internal Combustion Engines and Fuel Technologies*. (InTech, 2013).