Engine Performance and Economic Impact Study of Gasoline-Like Tyre Pyrolysis Oil in Thailand

C. Wongkhorsub, N. Chindaprasert, S. Peanprasit

Abstract— **The purpose of this paper is to study the comparing performance and efficiency of small gasoline engine using gasoline blended with Gasoline-like tyre pyrolysis oil (GTPO) in difference blended ratios. The comparisons of economic impact of using the blended oils are also investigate. The Blended GTPOs are compared with gasoline produced in Thailand by testing in gasoline engine (Honda GX140, four stoke, multi-purpose one cylinder, 144 CC). The testing is done by comparing performance of fuel which are torque, engine break power, fuel flow rate, generator output, BSFC (brake specific fuel consumption) based on the 3000 rpm engine rate. The result of the experiment shows that the torque output of the 100% blended GTPO is 94.2% lower compare to the normal gasoline, the BSFC of the 100% blended GTPO is 1.3% higher than normal gasoline but the thermal efficiency of the 100% blended GTPO is 1.86% higher than normal gasoline. Therefore, it is found that the 100% GTPO can be used to replace the normal gasoline in small engine but the best blended GTPO use in the engine is 25% blended ratio as the engine run smoothly in long term without wax and tars in the engine.**

Index Terms—**Pyrolysis, Gasoline-Like Tyre Pyrolysis Oil, Engine Performance, Energy Cost.**

I. Introduction

The fast depletion of petroleum fuel and the environmental issues have led to an intensive search for alternate fuels for internal combustion engines. One of the methods to derive alternate fuels is the conversion of waste substances to energy. Biomass based fuels like methanol, ethanol etc. are some of the examples in which waste to energy is adopted, and these are used as alternate fuels for the internal combustion engines. On the other hand, due to the increase in automotive vehicle population, the disposal of waste automobile tyres has become essential. In Thailand, it is found that there are about 56.7-170 millions tyres has been discarded per year or approximately 1.7 million tons per year [1].

Different alternatives for tyre recycling, such as retreading, reclaiming, incineration, grinding, etc., have been used. However, all these methods have significant drawbacks and limitations. Pyrolysis can be considered as a non-conventional method for tyre recycling, which is currently receiving renewed attention. In the pyrolysis process mainly the rubber polymers are heated and decomposed to low molecular weight products, like liquid or gases, which can be useful as fuels or chemicals source. In the past, several laboratory, pilot plant and even commercial attempts have been made to establish economic units for pyrolysis of tyres[2]. Tire pyrolysis has been investigated for more than 20 years. The process converts waste tire into potentially recyclable materials such as flammable gas, pyrolysis oil and carbon black [3]. Composition of the oil depends on reactor design and operating condition. Tire pyrolysis oil plant has been established around the world in order to produce the substitute liquid fuel for heating purpose as found that the tire pyrolysis oil have a high gross calorific value (GCV) of around 41-44 MJ/kg [4]. Desulfurization process is needed for tire pyrolysis oil as the high concentration of sulfur in pyrolysis oil leads the emission of SO_2 and sulfate particular matter. The main purpose of the commercial scale of the pyrolysis oil is used as a replacement of bunker oil. Therefore, the tyre pyrolysis plant is not widely established due to the product usage and economic of scale. However, the attempt of developing tyre pyrolysis oil has been made by applying some catalysts for the purpose of product yield distribution and quality of the oil[5], distilling the tyre pyrolysis oil to become diesel-like tyre pyrolysis[6][7].

The use of the tyre pyrolysis oil has been research in diesel engine and found the potential of using the diesel-like tyre pyrolysis to replace the diesel oil in small diesel engine [8][9]. However, one of the by-product of distilling the pyrolysis oil is naphtha oil. It is used primarily as feedstock for producing gasoline. Thus, the researcher is investigating the potential of using the naphtha or the gasoline-like tyre pyrolysis oil in small gasoline engine in order to be an alternative fuel for the small scale agriculture engine.

This paper presents the engine performances with energy output in kilowatt-hour applying blended various compositions of gasoline-like tire pyrolysis oil (GTPO) and diesel oil in agriculture gasoline engine. The gasoline-like tire pyrolysis oil was researched by distilled the tyre pyrolysis oil between 50-200°C so as to obtain the gasoline-like tyre pyrolysis oil. The economic analysis is investigated in terms of cost of fuel compare with energy output in kilowatt-hour applying blended various percentage of the GTPO and gasoline in small gasoline engine in order to predict the behavior of cost in each blended oil.

II. Tyre Pyrolysis

A. Gasoline-like Tyre Pyrolysis Oil(GTPO)

Pyrolysis process is a chemical and thermal process that reacts to decompose organic material under oxygen-free conditions. The products of pyrolysis include oils, gases and char. For tire pyrolysis oil, it has been researched that the tire

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C. Wongkhorsub, N. Chindaprasert, and S. Peanprasit are with the Department of Mechanical Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Thailand (e-mail: chonlakarn.w@rmutp.ac.th, nataporn.c@rmutp.ac.th)

pyrolysis oil is a complex mixture of organic compounds of 5-20 carbons with high proportion of aromatics [10].

The process of tyre pyrolysis is started from collecting the waste tyre and shred it to small pieces to be suitable to feed in to the pyrolysis reactor. In general, product yields from pyrolysis are varied with temperature. The oil production yield of tire pyrolysis process has a maximum at 350°C and decomposes rapidly above 400°C [11]. The pyrolysis oil used in this research is processed from a batch pyrolysis reactor with desulfurization process. The tyre pyrolysis oil sample was prepared using a commercial tyre pyrolysis plant in Thailand. The average product yield of tyre pyrolysis process is distinguished into 3 types of product as shown in Fig.1.

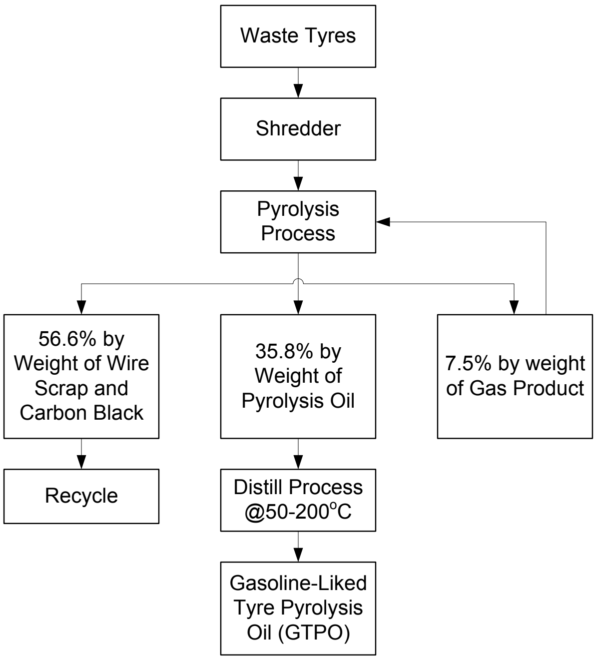

Fig. 1. Process and Avarage Product Yield of Tyre Pyrolysis Process.

The sample oil was distilled by flash distillation method at temperatures between 50-200°C respect to the distill temperature of light to heavy naphtha (C6-C14) without reforming process and additives.

B. GTPO Blending and Properties

The GTPO from pyrolysis and distill process is blended with the commercial Gasoline in Thailand in the variation of GTPO 10%, 25%, 50%, 100% by volume. The basic properties of the blended oil in ratio variation were analyzed and compared to gasoline by the loboratory of Energy Technology Department, Thailand Institute of Scientific and Technological Research, as shown in Table 1.

TABLE I: THE PROPERTIES OF THE GTPO BLENDED WITH GASOLINE

Fuel	LHV (Kcal/kg)	Density	Flash Point °C	C	H	O
100% GTPO	12,162	0.73	25>	82.0	11.4	6.1
50% GTPO	11,784	0.724	25>	82.3	11.6	5.7
25% GTPO	11,542	0.720	25>	82.1	11.8	5.8
10% GTPO	11,425	0.706	25>	83	11.8	5.0
Gasoline	11,361	0.703	25>	84.5	11.8	3.6

III. METHODOLOGY

A. Engine Performance

Engine performance indicates the effects of a oil in the engine. The determination of the engine performance in this experiment are break torque (T), engine break power (P), break specific fuel consumption ($Bsfc$), and break thermal efficiency (η_{th}). These several parameters can be obtained by measuring air and fuel consumption, torque and speed of the engine, and heating value of the oil. The performance parameters can be calculated by equations as followed [12][13].

Break torque (T) is an indicator of the function of break torque in Nm calculated by the moment of engine arm connected to weight scale as:

$$T = Fd \quad (1)$$

Where F is force of engine arm applied to the load in N, and d is the distance of engine arm from center of the rotor to the load.

Engine break power (P) is delivered by engine and absorbed load. It is the product of torque and angular engine speed where P is engine break power in kW, N is angular speed of the engine in rpm as:

$$P = \frac{2\pi NT}{60 \times 1000} \quad (2)$$

Break specific fuel consumption ($Bsfc$) is the comparison of engine to show the efficiency of the engine against with fuel consumption of the engine in g/kW-hr where ($\dot{m}_f$) is the fuel consumption rate in g/hr as:

$$Bsfc = \frac{\dot{m}_f}{P} \quad (3)$$

The percentage of break thermal efficiency of the engine (η_{th}) is related to engine break power (P) and the total energy input to the engine which is Q_{LHV} lower heating value of fuel in kJ/kg applied to the fuel consumption rate as:

$$\eta_{th} = \frac{P \times 1000}{\dot{m}_f Q_{LHV} \times 3600} \times 100 \quad (4)$$

B. Economic Impact

The economic impact of this research is done under the approach of comparing the energy cost of using the variation of GTPO as a fuel for gasoline engine. However, the energy consumption rate of each fuel are difference therefore, the best indicator that is suitable for all situations to predict the use of oil in terms of economic analysis should be energy cost consumption per power output as:

$$\varphi_E = bsfc \times \left(\frac{Cost_{PO}}{\rho_{PO}} \right) \quad (5)$$

Where φ_E is the cost of energy consumption per power output in Baht/kW-hr, ρ_{PO} is the density of calculating oil. Equation (5) shows the cost of energy compared regarding to the efficiency.

IV. Experimental Set up

This experimental research is designated to apply the GTPO in small scale Gasoline engine and study the experimental result of using the variation of GTPO as fuels. Therefore, engine specification, schematic of the engine measurement, engine operating condition and experimental results are described in this part.

A multi-purpose agricultural 4-stroke, overhead single cylinder gasoline engine (Honda GX140) is used for the experiment. The engine specifications are shown in Table II.

TABLE II: Engine Specification

Engine Description	Specification
Engine Brand	Honda GX140
Bore x Stroke	64 mm. x 45 mm.
Swept Volume /Cylinder	144 cc.
Max. Output, HP/rpm	5(3.7) /3600
Max.Torque @2800 rpm	1.0 kg-m
Ignition system	Ignition Coil
Heat Exchanger Sytem	Air Type
Fuel Consumption	0.81 Gallon/Hr.
Weight	14 Kg.

Schematic of the experimental set up is shown in Fig. 2. The engine equipped with measuring elements including weighing device, manometer, orifice plate, tachometer, thermocouple and thermocouple at the exhaust.

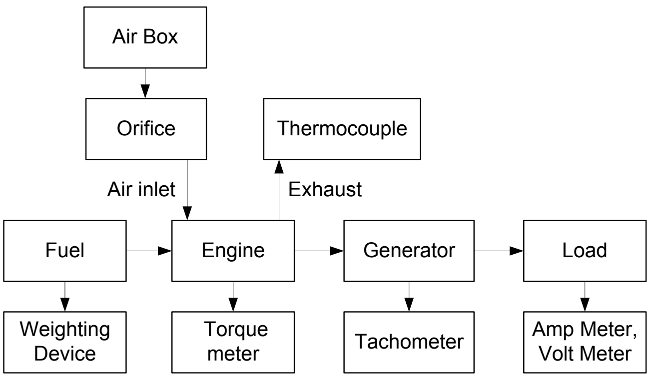

Fig. 2. Schematic of the experimental setup

As the experiment was operate in constant speed, the torque output from the experiment is measured by the breaking force absorbed by the load. The absorbed load is produced by a set of 5x100W light bulbs and 13x500W light bulbs connect in series together in order to vary the absorbed load.

The blended GTPOs with the commercial Gasoline in Thailand in the variation of GTPO 10%, 25% 50% 100% by volume were applied in the experiment. The experiments were conducted by starting engine with the sample fuel. The operating conditions were set at a rated engine speed 3000 rpm.

Loads were applied from 500 W and stepped up until reached the maximum load. The power output is measured by the watt meter which is lower than the load regarding to the efficiency of the generator. The air box is applied to stabilize the air flow into the engine as the air box volume is 500 times the volume of the engine cylinder. Orifice plate flow meter is applied for air flow measurement. Fuel consumption is measured from the differential of the fuel in time. A chromel-alumel thermocouple was installed to measure the exhaust gas temperature. At the end of the test the engine was run with gasoline fuel for a while to flush out from the engine.

V. Experimental Result

The Stoichiometric Air-fuel Ratio of fuel is calculated regarding to the properties of the blended oil in table I are shown in Table III.

TABLE III: Stoichiometric Air-fuel Ratio of fuel

Fuel	Gasoline	10% GTPO	25% GTPO	50% GTPO	100% GTPO
AF_{Stoich}	13.647	13.435	13.305	13.274	13.161

The stoichiometric air fuel ratio of the variation of the fuels in this experiment shows that the Gasoline obtains the highest number whereas the 100% GTPO is the lowest number. Therefore, this number could predict the trend of fuel consumption rate of each fuel. The more ratio of GTPO causes the high fuel consumption.

The experimental testing shows that the engine performance of variation of GTPO blended fuels are comparable to the gasoline. The trend of engine performance which are torque, break specific fuel consumption and the thermal efficiency of all testing oils including 100% GTPO is in the same direction. It shows that the GTPO is able to use as a replacement of the gasoline in term of engine efficiency. Fig.3. illustrates the relation of the break specific fuel consumption and the engine break power. Fig. 4 illustrates the thermal efficiency of the fuels in various engine break power. The thermal efficiency of the GTPO is higher than the gasoline by reason of the wide range of distillation temperature might cause pre-ignition and knocking.

Though the engine performance of the GTPO is comparable to gasoline, there are some physical limitation that found in the experiment that might affect using the GTPO in long term. It is shown in Fig. 5. that the exhaust temperature of the GTPO is slightly higher than gasoline also, the engine needs to be flushed off with gasoline after the experimental testing of GTPO due to the wax occurred in engine.

The optimum load for using blended GTPO and gasoline in this experiment is at the engine brake power range of medium load, 1,300 - 1,700 W as it performs well in terms of Bsfc and thermal efficiency. The thermal efficiency of gasoline is lower than the blended GTPOs due to the lower heating value as shown in table I.

The result of the experiment shows that the torque output of the 100% blended GTPO is 94.2% lower, the BSFC of the 100% blended GTPO is 1.3% higher than normal gasoline but the thermal efficiency of the 100% blended GTPO is 1.86% higher than normal gasoline in average load.

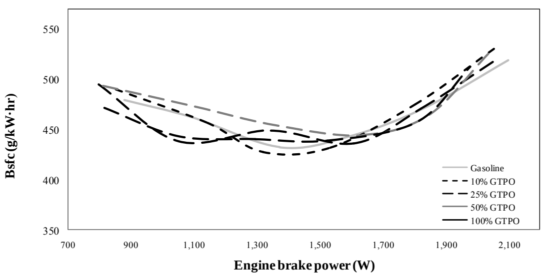

Fig. 3. Variation of brake specific fuel consumption with engine brake power.

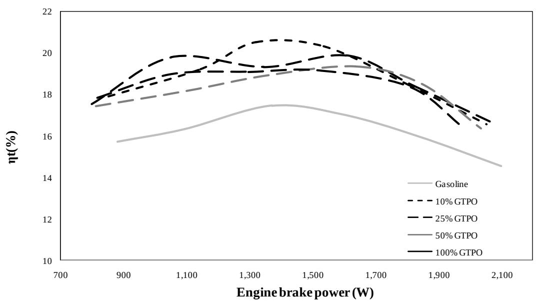

Fig. 4. Variation of thermal efficiency with engine brake power.

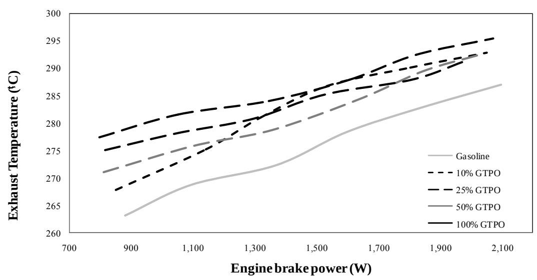

Fig.5. Variation of exhaust temperature with engine brake power.

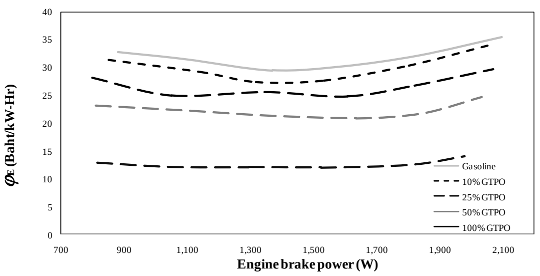

Fig. 6. Variation of the cost of energy consumption per power output with engine brake power.

The torque output of the 25% blended GTPO is 98.2% lower compare to the normal gasoline, the BSFC of the 25% blended GTPO is 0.32% higher than normal gasoline in medium load but the thermal efficiency of the 100% blended GTPO is 0.27% higher than normal gasoline in average load. It shows that the 25% blended GTPO has engine performance similar to the pure gasoline.

As found in the experiment that the GTPO is potentially replacing gasoline, the cost of GTPO is another concerned factor. Since the fuel consumption of the sample fuels are varies, the research use energy cost consumption per power output to indicate the economic impact of the samples. The GTPO cost is 20 Baht per liter whereas the gasoline cost is 48 Baht per liter. The energy consumption cost indicates that the use of GTPO is economically comparable to gasoline. Though the engine performance of the blended GTPOs is slightly lower than gasoline, the cost of fuel is significantly lower as shown in Fig. 6.

VI. Conclusion

Regarding to the engine performance, operating condition and the economic comparison, the potential blended GTPO is 25% blended as the engine performance is similar to normal gasoline but the cost of oil is 16.6% lower than gasoline.

However, the experimental testing of the GTPO compares to gasoline demonstrates that the GTPO is a potentially substitution of the gasoline in terms of engine efficiency. The GTPO in this research has been distilled by flash distillation which might cause the instability effect of the oil. Therefore, the GTPO should be improved by chemical process and distill in commercial scale distillation plant in order to obtain quality GTPO if the purpose of the oil production is for sale in commercial scale. It should be respected that the GTPO is produce from one source of waste. The using GTPO is one of the options to turn waste to energy which not only obtain the energy but also reduce the waste from the area. The environmental value of the product should be added to the economic impact study. The environmental impact in terms of pollution at the exhaust is also another concerning factor as the tyre pyrolysis process requires desulfurization.

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C. Wongkhorsub is a lecturer in Mechnical Engineering Department, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Thailand. She received her Ph.D. in Renewable Energy from the University of Nottingham in 2006. Her research focuses on renewable energy related on biomass and thermal system.