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A comparative assessment of single cylinder diesel engine characteristics with plasto-oils derived from municipal mixed plastic waste

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ABSTRACT

Recycling of municipal mixed plastic waste (MPW) is an emerging technology for conversion of waste to wealth. In the current study, MPW was processed to produce plasto-oils (PO_1 and PO_2) by thermochemical depolymerization in a batch production of 0.5 ton/batch. These oils were used in a 3.7 kW rated power single cylinder direct injection compression ignition (CI) engine to assess performance, combustion and emission behavior of the engine. The experimental results with plasto-oils were compared with base diesel fuel operation at different brake mean effective pressures (BMEPs) of 1.8, 3.8, 5.8, 7.8 and 10.8 bar. It is explored that brake thermal efficiency of the test engine with plasto-oils was almost comparable with the diesel fuel at all engine loads. Carbon based emissions such as unburnt hydrocarbon (HC), carbon monoxide (CO), and smoke emissions from the engine at 3.8–10.8 bar BMEPs were slightly higher with plasto-oils than diesel fuel. Nitrogen oxides emission decreased faintly with the use of plasto-oils at medium and high BMEPs (5.8–10.8 bar). However, at lower BMEPs (1.8–3.8 bar), emission behavior of the engine (HC, CO, smoke and NO_x emissions) was same with all kinds of fuels (diesel, PO_1 and PO_2). Overall, it is ascertained from the study that the plasto-oils exhibited a comparable performance with the conventional diesel fuel, which further promises its viability to use as a fuel candidate for CI engines.

1. Introduction

Mixed plastic waste (MPW) to fuel conversion by thermochemical route is a promising technology to cater the energy demands in industrial, transportation, and agriculture sectors. However, segregation of mixed-wastes and material variability are the significant impediments for widespread of the technology. At other hand, processing of single-plastic wastes with known physiochemical properties is easiest way to recycle and reuse, but collection of these single-plastic wastes from the end users will not be cost effective [1]. Technically, it is possible to separate mixed-wastes into recognizable streams, but it needs an efficient collection and separation-infrastructure, which is costlier [1–4]. Hence, variability and investment cost of separation-infrastructure are the major problems associated with MPW treatment towards wealth generation. It is noted that some technologies have been developed to separate the mixed wastes and further processing. For example, Tribo-charging and electrostatic separation technology was used by Silveira et al. to separate different combinations of plastics (HDPE/PP, LDPE/PP, and PET/PVC) [5]. Similarly, various other technologies including biological treatment were discussed by Florian et al. to separate the engineered nanomaterials from municipal solid waste (MSW) [6]. Bonifazi et al. worked to recognize different polymer flakes from MPW through an innovative hierarchical classification strategy based on hyperspectral imaging for separating low density polyethylene (LDPE) and high-density polyethylene (HDPE) [7]. Thus, many technologies are available for separation of MPW into recognizable streams, but employment of these technologies for handling low valued plastics may not be an economical viable option [8,9]. In addition, material compatibility is another challenge to be addressed for MPW conversion to wealth. It may be noted that during conventional recycling process, most plastic materials are not compatible with other plastic materials. For example, the presence of small amounts of Polyvinyl chloride (PVC) contaminants in polyethylene terephthalate (PET) recycle stream will degrade the complete PET resin by becoming

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Nomenclature

$\frac{\partial q}{\partial x_1}, \frac{\partial q}{\partial x_2}, \ldots, \frac{\partial q}{\partial x_n}$	partial differential of calculated parameter q which depends on different measured variables $x_1, x_2, \ldots, x_n$.
aBDC	after bottom dead center
aTDC	after top dead center
bBDC	before bottom dead center
BMEP	brake mean effective pressure, bar
BSFC	brake specific fuel consumption, kg/kWh
bTDC	before top dead center
BTE	brake thermal efficiency,%
CA	crank angle
CI	compression ignition
C_p	specific heat at constant pressure, J/kg-K
CV	Calorific value, kJ/kg
E_a	activation energy, kJ
k_1, k_2, k_3	constants
ME	mechanical efficiency,%
RR	reaction rate
R_u	universal gas constant, J/kg-mol K
R	characteristic gas constant, J/kg-K
T	in-cylinder temperature, K

yellowish and brittle that requires reprocessing. This indicates that the handling of MPW via conventional recycling technology is very much sensitive to the contaminants, which further requires some additional setups for separation of plastic wastes based on kind of resin, colors, and transparency [10,11]. In order to address all these problems, researchers and industrialists are striving to convert directly the MPW to fuels/energy/wealth with efficient and low cost technologies [10,12,13].

Very few researchers worked for fuels/energy production from MPW feedstocks. Kaminsky et al. produced oil and gaseous products via pyrolysis process in a fluidized bed reactor with MPW, which was collected from German households [14]. They achieved the maximum oil yield about 48% at 730 °C reaction temperature. They obtained the output products of benzene, toluene, xylenes and styrene with a total yield of 31.4% by weight [14]. Similarly, Demirbas also obtained the maximum oil yield about 47% with the mixture of plastic materials (polypropylene: PP, polyethylene: PE, and polystyrene: PS) collected from landfill [15]. Donaj et al. investigated on pyrolysis of MPW (that contains 75 wt% LDPE (low density polyethylene), 30 wt% HDPE, and 24 wt% PP) in a fluidized quartz-bed reactor at laboratory scale with the temperature range of 650–730 °C [12]. They also attained the maximum liquid yield about 48% at 650 °C reaction temperature [12]. A clear conclusion may be drawn from these studies that pyrolysis process produces lower oil yields (≤ 50%) with MPW feedstocks than single-plastic feedstocks (oil yield range: 60–70%). In support to this fact, Anuar Sharuddin et al. conducted a review study on the potential of energy conversion of different plastic waste materials (PP, PE, PS, PET, PVC, HDPE, LDPE and MPW) into valuable liquid products [16]. They concluded that PET and PVC were the two plastics that produced very low oil yield as compared to other plastic materials. It was also

Table 1
Summary of plastics derived pyrolysis liquid fuels use in CI engines.

Engine specifications	Fuels used	Major findings	Reference
Type: Single cylinder CI engine P: 3.68 kW; N:1500 rpm; CR: 16:1	Waste plastic PO diesel blends (10, 20, and 30 vol%)	• No significant power reduction observed • BTE (Brake thermal efficiency) and ME (Mechanical efficiency) increased with 20% plastic oil (PO) diesel blend as compared to diesel alone.	[21]
Type: Twin cylinder CI engine P: 10 HP; N:1800 rpm; CR: 17.5:1	Waste plastic PO diesel blends (10, 20, and 30 vol%)	• BTE and ME increased with all blends as compared to base diesel fuel operation • CO, CO_2 and HC emissions decreased significantly with the PO blends • 20% PO-diesel blend showed better performance as compared to other blends.	[22]
Type: Single cylinder CI engine P: 4.4 kW; N:2200 rpm; CR: 23.5:1	Tire and plastic POs(Up to15 vol.%)	Plastic PO offered lower engine performance. However, tire pyrolysis offered comparable efficiency to diesel fuel in medium to high load	[25]
Type: 4-cylinder CI engine P: 68 kW; N:1500 rpm; CR: 17:1	Waste plastics oil at different shares	• The engine was able to run on PO at high loads presenting similar performance to diesel while at lower loads the longer ignition delay period caused stability issues • At full load, BTE with PO was slightly lower than diesel; however, NO_x emission was considerably higher	[26,27]
Type: Single cylinder CI engine P: 7.5 kW; N:1500 rpm; CR: 17.5:1	Oil from kaolin-catalyzed pyrolysis of waste polypropylene (up to 50% Oil share)	• The engine showed better performance up to 30% PO-diesel blend, but beyond 50% blend knocking problem encountered • A stable BTE similar to that of diesel was observed up to 80% load • All emissions were considerably higher than that of the diesel baseline especially at high load	[35]
Type: Single cylinder CI engine P: 5 HP; N:1500 rpm CR: 17.5:1	Oil from waste plastics	• The engine could operate with neat waste PO and their blends without modifications • 10% waste PO-diesel blend showed similar results as compared to diesel	[38]
Type: Single cylinder CI engine P: 3.7 kW; N:1500 rpm; CR: 19.5:1	Waste plastic oil diesel blends (up to 100%)	• BTE of the engine with all PO-diesel blends and neat plastic oil was lower than diesel at all loading conditions • At full load, peak cylinder pressure, heat release, combustion duration and ignition delay of PO and its blends were higher than that of diesel • Peak pressure of the engine running on neat plastic oil was increased by 6% but it showed poor thermal efficiency	[33]
Type: 4-cylinder CI engine P: 89 kW; N:3200 rpm	Oil produced from waste polyethylene blended with diesel	• CO emission decreased by about 20% • CO_2 and NO_x emissions increased about 3%, and 9% with 5% waste PO-diesel blend as compared to diesel fuel	[36]
Type: Single cylinder CI engine P: 7.4 kW; N:1500 rpm; CR: 19.5:1	Oil from waste HDPE	• BTE of the engine at all loads were lower as compared to diesel fuel • NO_x and CO increased with increasing PO share, but HC increased	[34]
Type: Single cylinder CI engine P: 4.4 kW; N:1500 rpm;CR: 17.5:1	Waste plastic oil diesel blends up to 70%	• NO_x was higher by about 25% and CO increased by 5% with waste PO compared to diesel fuel operation • At full load, HC and smoke increased by 15% and 40% with the PO as compared to diesel operation • Engine fueled with PO exhibited higher BTE up to 80% load	[28–30]