Energy Conversion Behaviour and Actions of Hydrogen Energy on Functional Performance of CI Engine for Energy Saving Applications

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**Abstract:** It is the situation for handling plastic waste, which is the major task to reduce and subjected to the recycling technique to prevent the ecosystem as evergreen. Waste plastic is one of the key toxins and affects the soil nature during the landfill. Due to this, plastic wastes are recycled via the pyrolysis technique and gain pyrolysis oil subjected to thermochemical treatment via the gasification process, found to be efficient hydrogen fuel for energy applications. A single-stage compression ignition engine with water-cooled and varied electrical loading (25, 50, and 75%) is utilized for hydrogen characteristics study. It is evaluated by 100:0, 90:10, 80:20, and 70:30 ratio of diesel: hydrogen. The influences of hydrogen fuel on engine behaviour, BSFC (brake-specific fuel consumption) / BTE (brake thermal efficiency) and emission performance were studied. It found that a 70:30 fuel ratio has better BSFC (0.51kg/hr), higher BTE (35%) and reduced carbon monoxide (0.0389 vol %), hydrocarbon (46ppm) and NOx emission (880ppm).

# Introduction

The usage of plastic-based materials has increased worldwide in various applications [1-3], and they face a problem for disposal due to their specific behaviour of non-degradable and toxic [4-8]. Plastic waste is a pollutant that affects environmental living [3]. Due to this impact, plastic material usage must be recycled [9-12]. Recently, plastic wastes were utilized to synthesize the pyrolysis oil fuel and suggested for energy applications [13-15]. Based on the chemical compositions of plastic, derived fuel was used as an alternative fuel for internal combustion engine applications [16-17]. The extracted fuel was subjected to blend with diesel fuel and evaluated its performance on energy applications [18-22].

The catalytic-assisted pyrolysis route utilized hydrogen synthesis as of waste plastic performance and was studied using activated Mgo and carbon. The results showed that improved hydrogen yield utilized as jet fuel was found to enhance thermal efficiency [23]. Plastic wastes were synthesized via pyrolysis under higher temperatures pyrolysis process associated with carbon and magnesium oxide catalysts. The influence of temperature & catalyst on the hydrogen yield of the pyrolysis reactor is experimentally measured. Its results are recorded by 49.5% improved efficiency compared to diesel fuel [24-26]. Due to up-cycling and chemical recycling of waste plastic for future energy applications, plastics were utilized for hydrogen fuel generation and had great potential to fulfil the energy demand [27]. The waste high-density polyethylene and its combinations were subjected to pyrolysis to gain hydrogen fuel increased up to 25wt% in auto-thermal conditions [28]. Solar simulator adopted hydrogen production system was executed with plastic as feedstock and subjected to Ni-Ti-Al catalyst. The output showed a 53.46% molar fraction in the Ti-Al catalyst [29-32]. The pyrolysis-derived waste plastic fuel was the future trend for transportation applications. It has great opportunities to fulfil the energy requirement in various applications [33-35]. Single-step microwaves adopted catalytic was used to convert plastic to hydrogen fuel. The results showed enhanced hydrogen yield [15]. Moreover, the pyrolysis technique successfully utilized waste plastics for energy generation, which is efficient and economical for plastic oil fuel generation [36-40].

The waste plastic management and recycling process related to hydrogen production and its processing techniques were discussed. The present research investigation uses the pyrolysis technique to synthesize the pyrolysis fuel from waste plastics and subject to gasification process found hydrogen gas. It was considered fuel for alternative and used by IC engine, and its diesel blending behaviour was experimentally measured. Meanwhile, engine emission characteristics were evaluated, and reduced carbon monoxide, hydrocarbon and nitrous oxide were found.

# Materials and Methods

The experimental operation layout for hydrogen synthesis from waste plastic with the assistance of a gasification setup is displayed in Figure 1. The first stage of plastic waste was collected and cleaned with water. Then, it was fed into a crusher machine. The plastic waste is sliced into small pieces and fed into pyrolysis feedstock. The feedstock was heated at 450ºC for 60 minutes, the plastic wastes were melted, and gas was produced. The produced gas subjected to thermochemical process found pyrolysis oil under constant stir catalyst. After, it was subjected to a gasification process with supercritical steam supplied and helped to generate a high hydrogen yield. The steam was mixed with the existing setup, and syngas were produced during this process. It consists of carbon monoxide, methane, and hydrogen gas. The gasification process with a higher processing temperature (600ºC) enhances the hydrogen yield. During this gasification process, the excess temperature was compensated by a heat exchange arrangement and passed to the membrane that helps separate the gas.

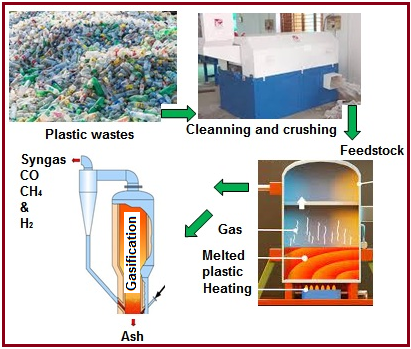


Fig. 1 Flow process diagram for hydrogen production from waste microalgae through a hydrothermal gasification process

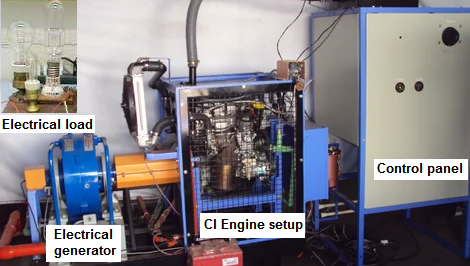


Fig. 2 Hydrogen-operated CI engine with electrical storage

The developed hydrogen was an alternative fuel blended with 0, 10, 20, and 30% diesel fuel. The blended hydrogen and diesel fuel were used in a single-stage CI engine coupled with an electrical generator, as shown in Figure 2. The impact of electrical loading on BSFC and BTE was experimentally evaluated [41-44]. Its emission performance of carbon monoxide, hydrocarbon and NOx emission are analyzed using a DI gas emission analyzer.

# Results and Discussion

## Gas yield from plastic waste

Fig. 3 illustrates the syngas (carbon dioxide CO2, carbon monoxide-CO, Hydrogen –H2 and methane –CH4) gained plastic wastes with an applied gasification temperature of 600ºC for a 60-minute process. It was recorded that the carbon monoxide was 1.1mol/kg with increased carbon dioxide and methane at 1.8 and 2.1mol/kg.

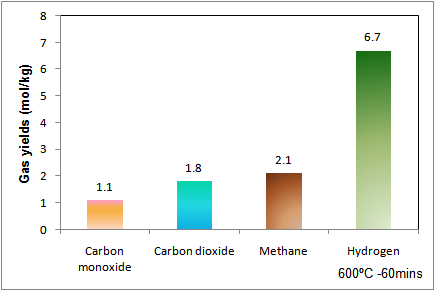


Fig. 3 Gas yield from plastic wastes

Compared to other gases, the hydrogen yield was 6.7mol/kg as the maximum and was improved by 2.19 times the methane yield. The effective pyrolysis with a high-temperature gasification process was the reason for the maximum hydrogen yield. The thermal behaviour of plastic and its process unit was the important desire to fix the hydrogen yield [45-50]. Introducing metal oxide with a neutralizer has minimized the effect of CO and CO2. Supercritical hydrothermal gasification helps to increase the hydrogen yield, and cyclone separator helps to separate the gas according to concentration gas.

Meanwhile, the effective pyrolysis associated with gasification found an optimum hydrogen fraction, and its gasification efficiency was 68%. Moreover, the hydrogen yield was hicked by 7% compared to past literature results. So, a higher gasification temperature (600ºC for 60 minutes) was recommended for hydrogen synthesis from plastic wastes. The catalyst selection was the reason for the maximum hydrogen yield.

## Effect of fuel blend on specific fuel consumptions of CI engine

Fig. 4 indicates the BSFC of CI engines operated by varied fuel blend ratios with increased electrical loading of 25 -75% with a 25% interval.

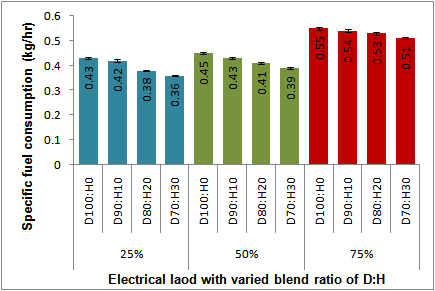


Fig. 4 Specific fuel consumption (Electrical load with varied diesel/hydrogen blend)

With varied fuel blends, the BSFC gradually decreased and increased with increased electrical loading. In 25% electrical loading, the BSFC was 0.43kg/hr and reduced as of increased blend ratio. Because of the impact of hydrogen fuel, it offered good thermal behaviour related to diesel fuel. While increasing the electrical loading by 50%, it showed higher fuel consumption than 25%. Moreover, fuel consumption increased when the load increased. The engine was operated under the safe limit; 75% electrical loading was considered the maximum condition. Due to this, the BSFC was recorded by 0.55, 0.54, 0.53, and 0.51kg/hr on increased hydrogen fuel blends of 0, 10, 20, and 30%, respectively. However, the concentration of hydrogen fuel in diesel fuel decreased BSFC under higher electrical loading conditions due to the significance of biohydrogen. The CI engine found higher performance, and the D70:H30 blend ratio consumed 0.51kg/hr and saved diesel fuel by 7.8%.

## Effect of fuel blend on brake thermal efficiency of CI engine

The influences of diesel blended with hydrogen fuel operated by different electrical loading on brake thermal efficiency as highlighted, Fig.5 and identified that the BTE of the CI engine was increased gradually with hikes in hydrogen blend and electrical load conditions. In 25% electrical load, the BTE of diesel fuel without blend was 23%, and blending of hydrogen as 10, 20, and 30% showed improved BTE of 26, 28, and 33%, respectively. Similarly, the 50% electrical loading with varied fuel ratio was observed as higher BTE than 25% electrical loading. D70:H30 with 50% electrical load was improved by 37.5% related to conventional fuel (diesel) due to their higher thermal behaviour of hydrogen fuel and its concentration [51-52].

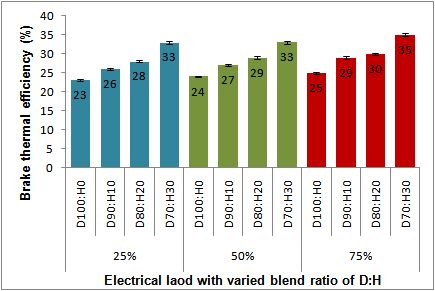


Fig. 5 Brake thermal efficiency (Electrical load with varied diesel/hydrogen blend)

However, the 75% safe electrical load condition with varied diesel fuel blend with hydrogen fuel showed a significant improvement in BTE, & the D70:H30 blend ratio found the optimum BTE of 35%. It was improved by 40% compared to diesel fuel without a hydrogen blend. So, the maximum ratio of hydrogen fuel blend found superior engine output performance, reducing specific fuel consumption.

## Effect of fuel blend on emission performance of CI engine

The influence of diesel blended with hydrogen fuel operated by different electrical loading on engine emission is shown in Fig.6. The carbon monoxide (CO) emission gradually decreased from 0.04 to 0.0389 vol%.

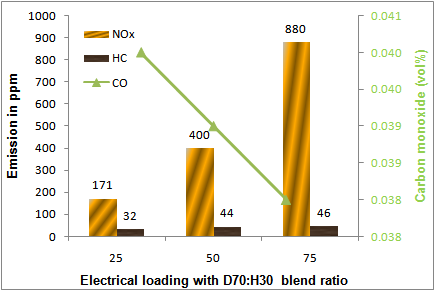


Fig. 6 Brake thermal efficiency (Electrical load with varied diesel/hydrogen blend)

So, this limit was considerable and related to diesel-operated CI engines. It was low. Similarly, the hydrocarbon and NOx were increased gradually with an uptrend of loading conditions with a D70:H30 blend ratio. Moreover, the hydrocarbon emission showed considerable improvement, which was the reason for the higher flash point of hydrogen fuel. The NOx showed 880ppm on maximum electrical loading; compared to diesel fuel, it was less than 1000ppm. So, it does not have a major effect on environmental pollution [53-54].

# Conclusion

The plastic wastes were effectively recycled using the pyrolysis technique and continued that gasification process with a maximum gasification temperature of 600ºC for 60 minutes. The hydrogen recorded by 6.7 mol/kg yield as maximum. The developed hydrogen fuel was mixed with diesel at 0, 10, 20, and 30% to replace diesel and was considered a fuel alternative for the CI engine. The influence of hydrogen fuel blend on BSFC & BTE was measured. It showed the minimum BSFC on 75% electrical loading with a D70:H30 blend ratio. Meantime, diesel fuel was saved 7.8%. The BTE of the D70:H30 mixed fuel ratio under 75% electrical load was improved by 40% related to conventional fuel (diesel). However, the emissions like CO, HC & NOx were limited and did not impact environmental pollution.

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