A Technical Review on Performance of CI Engine Fuelled with Plastic Pyrolysis Oil & Effect of Injection Pressure on Performance of CI Engine Fuelled with Diesel

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Abstract— Plastic Pyrolysis Oil is a fuel which can be used as a replacement of Diesel Fuel in CI engine. Plastic wastes can be converted into fuel oil by Pyrolysis process and the same can be used as a replacement of Diesel. Research has shown that properties of Plastic Pyrolysis Oil Depends upon type of the plastic waste used to convert them into fuel by pyrolysis process and these properties are nearly similar to Properties of Diesel fuel. So, by the use of Plastic Pyrolysis oil we can save the conventional Diesel Fuel and at the same time, we can reduce the amount of solid plastic wastes. Further, changing the injection pressure affects the performance of CI engine, the research shows. So by reviewing research on effect of injection pressure, we can improve performance of CI engine and it would be even more helpful in saving the consumption of Fuel.

Key words: Plastic Pyrolysis Oil, Diesel, Diesel Engine, Performance of CI engine

I. INTRODUCTION

Use of plastic in our daily activities seemed to be increased from years. In an online article, dated April 4, 2013 of the daily newspaper The Times of India of the author Dhananjay Mahapatra it was stated that '"We are sitting on a plastic time bomb," the Supreme Court said on Wednesday after the Central Pollution Control Board (CPCB) informed it that India generates 56 lakh tonnes of plastic waste annually, with Delhi accounting for a staggering 689.5 tonnes a day. "Total plastic waste which is collected and recycled in the country is estimated to be 9,205 tonnes per day (approximately 60% of total plastic waste) and 6,137 tonnes remain uncollected and littered," the CPCB said. This waste is a source of continuing pollution as plastic is not bio-degradable and poisons the environment for decades. The CPCB said a survey conducted in 60 major cities found that 15,342.46 tonnes of plastic waste was generated every day, amounting to 56 lakh tonnes a year. [1]

The energy crisis as well as the environmental degradation are the major problems mankind is facing today. Demand of energy has been increased day by day because of the increased population on the earth. By the year 2100, the world population is expected to be in excess of 12 billion and it is essential that the demand of energy will be increased by five times of what it is now. According to the world energy report, we get around 80% of our energy from conventional fossil fuels like oil (36%), natural gas (21%), and coal (23%). It is well known that the time is not so far when all these sources will be completely exhausted. The alarm bells have started ringing as survey indicates that petroleum will become increasingly scarily beyond present rate of consumption.

These problems indicate that the initiatives to replace gasoline and diesel fuel, due to the impact of fossil fuel crisis, hike in oil price and stringent emission norms, must be taken. Solution to long term energy problem will come only through research and developments in the field of alternative energy sources. Waste to energy is the recent trend in the selection of alternate fuels. One such fuel is Pyrolysis oil, which can be obtained from plastic waste as an alternative fuel. By using Plastic Pyrolysis Oil as a replacement of Diesel, both the above stated problems can be solved at great extent.

II. REVIEW ON PLASTIC WASTE

According to the research paper published by Mufeed Sharholy, Kafeel Ahmad, Gauhar Mahmood & R.C. Trivedi, named "Municipal solid waste management in Indian cities – A review" [2], which was published on Elsevier under waste management category, an average 3.9% of plastic wastes are characterised (% by weight) of total Municipal Solid Wastes. The average stated above was of 23 metro cities and this report was published by Central Pollution Control Board (CPCB) in the year 2000.

In a report on "Assessment of Plastic Waste and its Management at Airports and Railway Stations in Delhi", which was published by CPCB IN December, 2009 [3], it was stated that 'The present study envisages data on Plastics Waste generated at three Railway Stations and two Airports in Delhi. About 6758 kg/day of Plastics Waste is generated in these 03 Railway Stations and about 3662 kg/day at the 02 Airports. The per capita Plastics Waste Generation is approximately 9 gm/day at Railway Station and 69 gm/day at Airport.' It was also stated in the report that 'The information collected from various sources were analysed and the present quantities of plastic waste generated are worked out. The quantity of plastic waste generated per day at H. Nizamuddin, Old Delhi and New Delhi railway station is 972 kg, 1,428 kg and 4,358 kg respectively. Out of these total quantities, the value added plastics (water and soft drink bottles) reported at H. Nizamuddin, Old Delhi and New Delhi railway stations is about 20%, 20% and 32% respectively. The per capita plastic waste generation at H. Nizamuddin, Old Delhi and New Delhi is 7.8 gm, 9.5 gm and 9.7 gm respectively'.

As per the report named "Website Material on Plastic Waste Management" published by CPCB in June, 2013 [4], 'Plastic products have become an integral part in our daily life as a basic need. It produced on a massive scale worldwide and its production crosses the 150 million tonnes per year globally. In India approximately 8 Million tonnes plastic products are consumed every year (2008) which is expected to rise 12 million tonnes by 2012. Its broad range of application is in packaging films, wrapping materials, shopping and garbage bags, fluid containers, clothing, toys, household and industrial products, and building materials. It is a fact that plastics will never degrade and remains on landscape for several years. The recycled plastics are more harmful to the environment than the virgin products due to mixing of colour, additives, stabilizers, flame retardants etc. Further, the recycling of a virgin plastic material can be done 2-3 time only, because, after every recycling, the strength of plastic material is reduced due to thermal degradation. It is to mention that no authentic estimation is available on total generation of plastic waste in the country however, considering 70% of total plastic consumption is discarded as waste, thus approximately 5.6 million tons per annum (TPA) of plastic waste is generated in country, which is about 15342 tons per day (TPD).

III. Review on Pyrolysis Process and Properties of Plastic Pyrolysis Oil

Bio-oil is produced via pyrolysis, a process in which biomass is rapidly heated to 450–500°C in an oxygen-free environment and then quenched, yielding a mix of liquid fuel (pyrolysis oil), gases, and solid char. Variations in the pyrolysis method, biomass characteristics, and reaction specifications will produce varying percentages of these three products. Several technologies and methodologies can be used for pyrolysis, including circulating fluid beds, entrained flow reactors, multiple hearth reactors, or vortex reactors. The process can be performed with or without a catalyst or reductant.

The original biomass feedstock and processing conditions affect the chemical properties of the pyrolysis oil, but it typically contains a significant amount of water (15%–30% by weight), has a higher density than conventional fuel oils, and exhibits a lower pH (2–4). The heating value of pyrolysis oil is approximately half that of conventional fuel oils, due in part to its high water and oxygen content, which can make it unstable until it undergoes further processing. Bio-oil can be hydro-treated to remove the oxygen and produce a liquid feedstock resembling crude oil (in terms of its carbon/hydrogen ratio), which can be further hydro-treated and cracked to create renewable hydrocarbon fuels and chemicals. Hydro-treating stabilizes the bio-oil preventing molecule-to-molecule and molecule-to-surface reactions and eventually produces a finished blend-stock for fuels. Bio-oil can be deoxygenated from its high initial oxygen content of 35-45 percent by weight (wt%) on a dry basis all the way down to 0.2 wt%. [5]

Author Donglei Wu et al [6] produced experimental setup for low temperature conversion of plastic waste into light hydrocarbons. For this purpose 1 litre volume, energy efficient batch reactor was manufactured locally and tested for pyrolysis of waste plastic. The feedstock for reactor was 50 g waste polyethylene. The average yield of the pyrolytic oil, wax, pyrogas and char from pyrolysis of PW were 48.6, 40.7, 10.1 and 0.6%, respectively, at 275 ◦C with non-catalytic process. Using catalyst the average yields of pyrolytic oil, pyrogas, wax and residue (char) of 50 g of PW was 47.98, 35.43, 16.09 and 0.50%, respectively, at operating temperature of 250 ◦C. Properties of Plastic Pyrolysis Oil is given in the following figure 1which is referred as WPO & it is compared with Diesel.[7]

Sr. No.	Properties	WPO	Diesel
1	Colour	Pale black	Orange
2	Specific Gravity at 30 °C	0.8355	0.84 to 0.88
3	Gross Calorific Value (kJ/kg)	44340	46500
4	Kinematic Viscosity, cSt @ 40 °C	2.52	2.0
5	Cetane number	51	55
6	Sulphur Content (%)	<0.002	<0.035
7	Flash Point °C	42	50
8	Fire Point °C	45	56
9	Pour Point °C	< 7	6

Fig. 1: Properties of Plastic Pyrolysis oil [7]

IV. Effects of Plastic Pyrolysis Oil and its Blend on the Performance and Emission Characteristics of CI Engine

Author C. Wongkhorsub & N. Chindaprasert [8] made a comparison of the use of pyrolysis oils in diesel engine in the assessment of engine performance, and feasibility analysis. Pyrolysis oils from waste tire and waste plastic were studied by them to apply with one cylinder multipurpose agriculture diesel engine. It was found that without engine modification, the tire pyrolysis offered better engine performance whereas the heating value of the plastic pyrolysis oil was higher. The plastic pyrolysis oil could improve performance by modifying engine. The economic analysis showed that the pyrolysis oil was able to replace diesel in terms of engine performance and energy output if the price of pyrolysis oil would not greater than 85% of diesel oil.

Authors have concluded in their research that, though the plastic pyrolysis oil offers lower engine performance, the plastic waste amount is enormous and it needed to be process to reduce the environmental problems. Moreover, the engine can be modify follow the combustion condition of plastic pyrolysis oil. The waste plastic used in the process must be PE or PP in order to protect the contamination of chlorine in the oil. They have also mentioned that Turning waste to energy is not only financial profit-able but it also environmental friendly business which the government should offer a strong policy to encourage the entrepreneur to invest in the waste to energy business.

Author M. Mani et al [9] performed an experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation. They performed the investigation to study the effect of cooled exhaust gas recirculation (EGR) on four strokes, single cylinder, direct-injection (DI) diesel engine using 100% waste plastic oil. Experimental results showed higher oxides of nitrogen emissions when fuelled with waste plastic oil without EGR. NOx emissions were reduced when the engine was operated with cooled EGR. The EGR level was optimized as 20% based on significant reduction in NOx emissions, minimum possible smoke, CO, HC emissions and comparable brake thermal efficiency. Smoke emissions of waste plastic oil were higher at all loads.

Author M. Mani & G. Nagarajan [10] studied the influence of injection timing on performance, emission and combustion characteristics of a DI diesel engine running on waste plastic oil. In their study, the influence of injection timing on the performance, emission and combustion characteristics of a single cylinder, four stroke, direct-injection diesel engine had been experimentally investigated using waste plastic oil as a fuel. Tests were performed at four injection timings (23°, 20°, 17° and 14° bTDC). When compared to the standard injection timing of 23° bTDC the retarded injection timing of 14° bTDC resulted in decreased oxides of nitrogen, carbon monoxide and unburned hydrocarbon while the brake thermal efficiency, carbon dioxide and smoke increased under all the test conditions.

V. Effect of Injection Pressure on the Performance of CI Engine Fuelled with Different Alternative Fuels

Author Avinash Kumar Agarwal et al [11] used a single cylinder diesel fuelled CI engine to experimentally determine the effects of fuel injection strategies and injection timings on engine combustion, performance and emission characteristics. The experiments were conducted at constant speed (2500 rpm) with two FIPs (500 and 1000 bars respectively) and different start of injection (SOI) timings. Cylinder pressure and rate of heat release (ROHR) were found to be higher for lower FIPs however advanced injection timings gave higher ROHR in early combustion stages. Brake thermal efficiency (BTE) increased with increased injection pressures while exhaust gas temperature and brake mean effective pressure (BMEP) increased up to 500 bars. These parameters reduced slightly with more increase in FIP. For advanced SOI, BMEP and BTE increased, while brake specific fuel consumption (BSFC) and exhaust gas temperature reduced significantly. Carbon dioxide (CO_2) and hydrocarbon (HC) emissions decreased however nitrogen oxide (NOx) emissions increased with increasing FIP. Lower CO_2 and HC emissions, and significantly higher NOx emissions were observed with advanced injection timings.

Author Wenming Yang et al [12] researched with fuel injection strategies for performance improvement and emissions reduction in compression ignition engines. The reason behind this research was to strike an optimum solution between engine performance and emissions. During this research they found out that increasing the fuel injection pressure can improve the fuel atomization and subsequently improve the combustion process, resulting in a higher brake thermal efficiency, producing less HC, CO, PM emissions, but more NOx emission. Pilot injection help in reducing combustion noise and NOx emissions and immediate post injection may help in soot oxidation and late post injection helps in regeneration of diesel particulate filter.

Author Kyunghyun Ryu [13] observed the effects of pilot injection pressure on the combustion and emissions characteristics in a diesel engine using biodiesel–CNG dual fuel. In a Dual Fuel Combustion (DFC) mode the combustion begins and ends earlier as the pilot-fuel injection pressure increases. The ignition delay in the DFC mode is about 1.2–2.6 °CA longer than that in the diesel single fuel combustion (SFC) mode. The smoke and NOx emissions are significantly reduced in the DFC mode. But with increase in Pilot injection pressure, we can reduce the ignition delay which also reduces the exhaust smoke and CO emissions. But increase in Pilot injection pressure increases NO_X emissions.

Author Özer Cana et al [14] observed, in their study of effects of ethanol addition on performance and emissions of a turbocharged indirect injection Diesel engine running at different injection pressures, the effects of ethanol addition (10% and 15% in volume) to Diesel No. 2 on the performance and emissions of a four stroke cycle, four cylinder turbocharged indirect injection Diesel engine having different fuel injection pressures (150, 200 and 250 bar) at full load were investigated. 1% isopropanol was added to the mixtures to satisfy homogeneity and prevent phase separation. Experimental results showed that the ethanol addition reduces CO, soot and SO_2 emissions, although it caused an increase in NOx emission and approximately 12.5% (for 10% ethanol addition) and 20% (for 15% ethanol addition) power reductions. It was also found that increasing the injection pressure of the engine running with ethanol–Diesel fuel decreased CO and smoke emissions, especially between 1500 and 2500 rpm, with respect to Diesel fuel, while it caused some reduction in power.

Author R. Anand and G.R. Kannan [15] used a blend of 30% waste cooking palm oil (WCO) methyl ester, 60% diesel and 10% ethanol (called as Diestrol) in the experimental evaluation of DI diesel engine at varying injection pressure and injection timing. Maximum brake thermal efficiency of 31.3% was obtained at an injection pressure of 240 bar and injection timing of 25.5° before TDC. Compared to diesel, diestrol fuel showed reduction in carbon monoxide (CO), carbon dioxide (CO_2) and smoke emission by 33%, 6.3% and 27.3% respectively. Diestrol fuel decreased nitric oxide (NO) emission by 4.3%, while slight increase in the levels of unburnt hydrocarbon (UHC) was observed. Diestrol fuel exhibited higher cylinder gas pressure and heat release rate compared to diesel. Minimum ignition delay of 12.7° CA was observed with diestrol fuel which was similar to diesel at same operating condition.

VI. Conclusion

According to above stated Literature Review, Plastic Pyrolysis Oil can be used as a replacement of a Diesel Fuel in CI Engine and thus we can save the consumption of Diesel Fuel. Further, variation in Injection pressure can positively affect the performance of Engine. Detailed conclusion can be stated as follows.

- Content of Plastic waste in total solid waste is seemed to be increasing day by day. This must be stopped or reduced in order to prevent the environment to be polluted for the sake of the mankind.
- Number of alternative fuels like Jatropha Methyl Ester (JME) and Tyre Pyrolysis Oil (TPO) blends, anchovy fish oil as a blended fuel, Transformer oil with diesel blends, Tyre Pyrolysis oil, Plastic Pyrolysis oil etc. can be used with varying different engine parameters to optimise the performance and emission characteristics.
- Increase in injection pressure of Engine with different alternative fuel decreases ignition delay and provides better performance as well as reduces

HC emissions. But NO_X content seemed to be increased with increase in injection pressure.

– Plastic Pyrolysis oil used without blend causes lesser performance and more smoke exhaust in standard engine parameters. Further, with EGR the exhaust temperature and NO_X can be reduced in the engine fuelled with Plastic Pyrolysis Oil. But the brake thermal efficiency decreases and HC content increases with increase in EGR rate.

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