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RESEARCH ARTICLE

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PERFORMANCE ANALYSIS OF SINGLE CYLINDER DIESEL ENGINE FUELLED WITH PYROLYSIS OIL/DIESEL/BUTANOL BLENDS

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ABSTRACT

Performance analysis of single cylinder diesel engine fuelled with pyrolysis oil/diesel and its blend with butanol has been carried out in this research. The pyrolysis oil was obtained from hard wood chips (mahogany and walnut). 90% diesel, 5% wood pyrolysis oil and 5% butanol were taken to prepare the first blend, 85% diesel-10%WPO-5%butanol was used for the second blend, same for 80% diesel-15%WPO-5%butanol, 75% diesel-20%WPO-5%butanolwhile 70% diesel, 25% wood pyrolysis oil and 5% butanol diesel were mixed to prepare the final blend. Readings were taken to determine the effect of pure diesel on specific energy consumption, fuel consumption, thermal efficiency, mechanical efficiency, exhaust gas temperature of internal combustion engine and compared with the effect of blended pyrolysis oil, diesel and butanol on same parameters on same engine. Major findings of the study include: the wood pyrolysis oil/diesel/butanol blend possess more combustible hydrocarbon than the pure wood pyrolysis oil. Based on the findings recommendations were made which include: the fast pyrolysis of biomass in the absence of oxygen has the potential to contribute to the world's need for liquid fuels therefore waste pyrolysis oil should be used as an alternate source of fuel to diesel in internal combustion engines. The pyrolysis oil - diesel blend is recommended for use in machines where mechanical efficiency, brake specific energy consumption and brake specific fuel consumption is priority.

Keywords: wood pyrolysis oil, alcohol, 3D contour modelling, energy, pyrolysis, diesel.

1.0 INTRODUCTION

Energy is an integral part and an important input in all sectors of any country's economy. The standard of living of a country can be directly related to per capita energy consumption. Energy crisis in recent years is due to the two reasons: first is that the population of the world has increased rapidly and secondly the standard of living of human beings has increased. Most developing countries at present export primary products such as food, cocoa, tea, jute, nuts, red oil and ores etc. This does not give them the full value of their resources in export. To get better value, the primary products should be processed to products for export, that is from raw materials to finished products and this needs energy.In ancient Egyptian times, tar for caulking boats and certain embalming agents were made by pyrolysis. Some decades ago, researchers found that the yield of pyrolysis liquid could be increased by fast pyrolysis where a biomass or bio-degradable feedstock is heated at a rapid rate and the vapour produced thereof is also condensed rapidly. Most of all transportation energy consumption in the world is derived currently from non-renewable petroleum. Fossil oil accounts for more than half of all oil used in the world today. It is true oil is non-renewable and most nationsare heavily dependent on fossil sources for energy, these are excellent reasons and incentives for researching, investing and developing renewable energy sources.Biomass for energy,in contrast to fossil fuels provides significant environmental advantages. Plant needed to generate biomass feedstock removes atmospheric carbon dioxide, which offsets the increase in atmospheric carbon dioxide that results from biomass fuel combustion. At present,there is no researched commercially viable way to offset the carbon dioxide added to the atmosphere (with the resultant greenhouse effect) due to fossil fuel combustion. The climate change effects of carbon dioxide from fossil fuels are now generally and globally recognized as a potential serious environmental problem.

2.0 Materials and Method

The electrical heater capacity that will heat up the combustion chamber is designed to generate between 2.0 – 2.5 kW with a temperature control setting for a maximum of 510^{0}C. The combustion chamber is built to contain 4kg of feedstock (in this case wood chippings) and the process time is 180 minutes. In many industrial applications, the pyrolysis process is done under pressure and at operating temperatures above 430 °C. For agricultural waste, for example, typical temperatures are 450 to 550 °C.In vacuum pyrolysis, organic material is heated in a vacuum in order to decrease its boiling point and avoid adverse chemical reactions[1]. This research adopted the vacuum pyrolysis process. For the present investigation, pyrolysis oil from waste wood chips was obtained by vacuum pyrolysis process. Thick wood obtained from mahogany and walnut (the two most common industrial wood waste) wood chippings were taken as raw materials, cut into small chips, washed and dried. These chips were fed into an externally heated reactor unit. The feed material was heated up in the reactor in the absence of oxygen or little/minimal presence of oxygen. The reactor used in the pyrolysis process is a fully insulated unit. The heat input to the electrical heater was between 2.0 – 25kW. The temperature of the reactor was measured with the help of a temperature indicator provided in a temperature controller unit. The pyrolysis process for deriving wood pyrolysis oil was carried out at 450^{0}C - 500^{0}C . The residence time it took for 1kg of the pyrolysis feedstock material to convert wood waste to wood pyrolysis oil is 150-180 minutes. The products of pyrolysis in the form of vapor were sent to a water cooled condenser and the condensed liquid was collected in a container and further processed to remove moisture.

Wood pyrolysis yields have been classified as gases; organic liquids, char and product water. High organic liquid yields are characteristic of all materials when undergoing fast pyrolysis. The total liquid yield, including water of reaction, varies from 70% to 80% of the dry biomass fed, all of which can be directly used as a substitute fuel oil if desired. The liquid is single phase, homogeneous fluid, which pours readily, and contains from 15% to 25% water depending on the feed material and its moisture content. These liquids are quite stable at room temperature. To remove the water content by evaporation, the oil is heated.The wood waste pyrolysis oil, butanol and diesel were then blended together. 5% butanol, 5% of the pyrolysis oil and 90% of diesel blend was prepared and used to run the engine. This was the first blend to be tested. Afterwards 10% pyrolysis oil is taken, 5% butanol and 85% diesel mixture gave the second blend that was tested too. These blends were tested on the same parameters as the pure diesel and their various readings noted.First, the reading was taken at no load on pure diesel and progressively the load is increased from 15% to 30% through to 75% by adjusting the governor. The Engine speed (rpm) is maintained at 1500rpm. The time (sec.) taken to exhaust 20ml of pure diesel under these parameters was noted. Likewise the exhaust temperature (^{0}C), fuel consumption (kg/hr.), brake power (kW), brake specific fuel consumption (g/kW.h), indicated power (Kw), mechanical efficiency (%), thermal efficiency (%), brake specific energy consumption were noted for each increment in load.The engine was coupled to an alternator to provide the loading. A control panel located near the engine helps to operate the alternator to provide the load to the engine by a load switch. The exhaust gas temperature was measured with the help of a thermocouple fitted on the exhaust pipe. Fuel was admitted from fuel tank to the engine through a fuel filter and fuel pump. The fuel consumption was measured with the help of a burette and a fuel sensor. A tachometer was connected near the flywheel of engine to measure the speed. Data collected like fuel consumption, speed, air flow and exhaust gas temperature for the corresponding loads were noted and recorded. All tests were carried out by starting the engine with diesel fuel only. After running the engine with different emulsions, the engine was run with diesel fuel to flush out the emulsion present in the fuel line.It should be noted that the run for each research parameter was performed at least three times and an average reading of the runs was determined and recorded against each parameter.

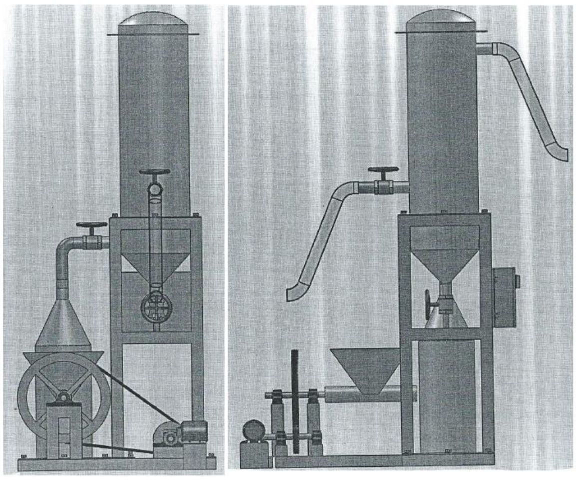

Figure 2.1: Front and Side View of the Wood Pyrolysis Reactor

3.0 RESULT AND DISCUSSION

Butanol addition significantly lowered combustion duration. It was found that butanol (ignition improver) forms a number of ignition centers in the combustion chamber before the ignition of wood pyrolysis oil (WPO) emulsion which resulted in reduced combustion duration. As blending increases, brake specific energy consumption increases for same brake power; this is because of the lower energy content of emulsion. Availability of more oxygen content in the fuel reduces the heating value. As the blending increases, exhaust gas temperature increases for same brake power; this is due to more oxygen availability in the pyrolysis oil.

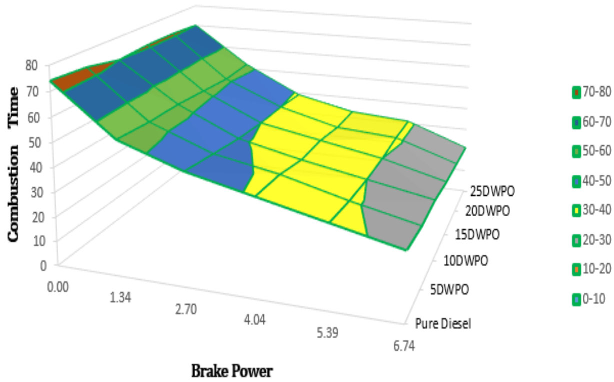

Fig 3.1: *Variation Combustion Time with brake power (3-D Surface Contour Modelling)*

There was higher fuel consumption when running on Wood Pyrolysis Oil, WPO-

Diesel, DF blends. This was due to the higher relative density and lower energy density of WPO. This may cause the increase in fuel consumption and decrease in combustion duration. The trends of the blends showed an increase in fuel consumption approximately proportional to the amount of WPO added to the diesel fuel.

It can be observed that the combustion duration decreases with WPO-butanol addition, which indicates faster heat release which leads to high thermal efficiency than diesel as indicated in the Fig 3.1. Butanol (ignition improver) forms a number of ignition centers in the combustion chamber before the ignition of WPO emulsion which may result in reduced combustion duration. Combustion duration was observed to be higher in WPO-butanol than in WPO-ethanol blend.

3-D Surface Contour Modelling shows a three-dimensional surface that connects a set of data points. It is useful when you want to find optimum combinations between two sets of data. It also shows trends in values across two dimensions in a continuous curve.

From the 3-D surface chart of fig 3.1, the optimum combustion time across all blends of the fuel is 30 – 40 seconds.

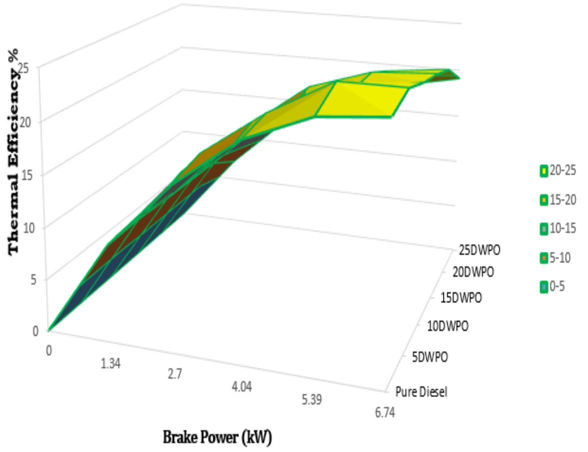

Fig 3.2: Variation brake thermal efficiency with brake power (*3-D Surface Contour Modelling*)

The brake thermal efficiency is lower for the emulsions compared to that of diesel at all loads. Addition of butanol to WPO emulsion decreased the viscosity of blends and resulted in improvement in the shape of fuel spray and atomization. These finer fuel droplets tend to mix thoroughly with air and hence improving the combustion. It can be observed from the Figure 3.2 that the brake thermal efficiency of diesel fuelled operation at full load is 23.6%. In case of WPO-diesel emulsions the brake thermal efficiencies of WPO emulsion with 10% pyrolysis oil and WPO emulsion with 20% pyrolysis oil at full load are 23.31%, and 21.51% respectively. Therefore brake thermal efficiency was reduced slightly due to the cooling effect of butanol.

At full load, the efficiency is higher for diesel fuel. This is due to the fact that at full load, the exhaust gas temperature and the heat release rate are marginally higher for wood pyrolysis oil, WPO compared to diesel. The total heat release for each WPO-Diesel Fuel blends is lesser than diesel. Hence, the brake thermal efficiency is lower for the WPO-DF blends than diesel. Because of the changes in composition, viscosity, density and calorific value of WPO-DF blends the brake thermal efficiencies of WPO-DF blends are low particularly at full load.

It can be explained that the reduction in brake thermal efficiency is due to high exhaust gas recirculation, EGR percentages. Exhaust Gas Recirculation,EGR involves recirculation of small amount of exhaust gas back into the intake stream[2].This is caused by deficiency in oxygen concentration in the combustion process and larger replacement of air by the exhaust gases. Higher flow rate of exhaust gases reduces the average combustion temperature in the combustion chamber resulting in reduction in brake thermal efficiency at all the loads.

Fig 3.2 also shows that the optimum thermal efficiency across all blends of the fuel is 20% – 25%.

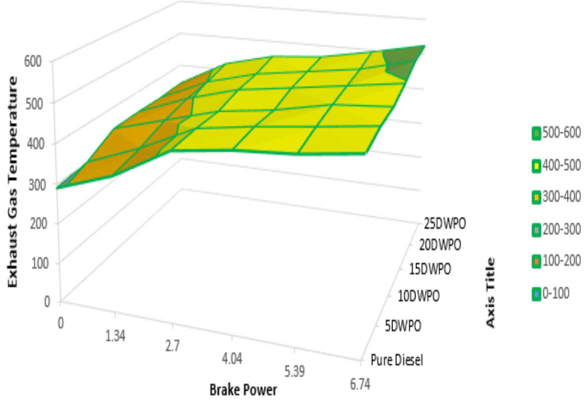

Fig. 3.3: Variation of exhaust gas temperature with brake power (*3-D Surface Contour Modelling*)

Exhaust gas temperature measured from the engine is an indication for the conversion of heat into work. Research on diesel and wood pyrolysis oil in diesel engine shows that the exhaust gas temperature varies from 290^{0}C at no load to 470^{0}C at rated power for diesel and for the wood pyrolysis oil it varies from 340^{0}C at no load to 490^{0}C for 10DWPO and 339^{0}C at no load to 519^{0}C for 20DWPO at rated power. The increase in exhaust gas temperature with engine load is clear from the simple fact that more amount of fuel was required by the engine to generate the extra power needed to take up the additional loading it is also find that the fuel air ratio is higher in the case of WPO compared to diesel at all loads.

This result in higher exhaust gas temperature in the case of wood pyrolysis oil compared to diesel. A research on waste plastic oil and diesel fuel blends in compression ignition engine, [3] proved that the exhaust gas temperature increases with load because more fuel is burnt to meet the power requirement. It is evident from figure 3.3 that the exhaust gas temperatures of the different WPO diesel emulsions are higher than diesel fuel operation. For WPO blend emulsion, the exhaust gas temperature varies from 340$^{\circ}C$ at no load to 490O°C at full load. The reason may be due to lower calorific value of the emulsion blends when compared with Diesel fuel, DF. Higher exhaust gas temperature in the case of WPO compared to DF is due to higher heat release rate, poor volatility and high viscosity. The increase may also probably be due to higher heat release rates of Wood Pyrolysis Oil-Diesel Fuel blends developed in the premixed combustion.

Also in the case of WPO, the fuel spray becomes finer and effective combustion takes place.

The 3-D surface chart of fig 3.3 shows that, the exhaust gas temperature time across all blends of the fuel is 400 – 500^{0}C.

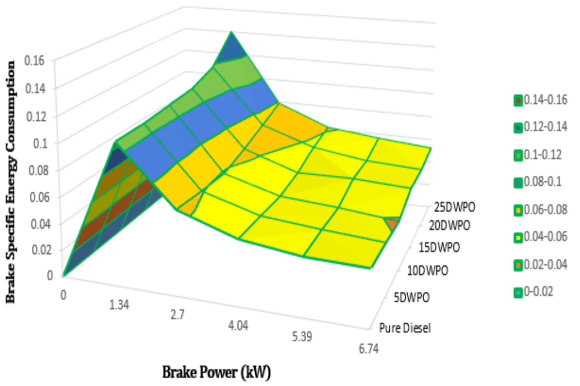

Figure 3.4: Variation of brake specific energy consumption with brake power (*3-D Surface Contour Modelling*)

BSEC is defined as the amount of energy consumed per kilo-watt power developed in the engine in one hour. For the comparison of economy of two fuels, brake specific energy consumption is the better way of judgment as compared to brake specific fuel consumption because the heating value and density of the fuels exhibit slight different trends.

The results of the brake specific energy consumptions with the engine power outputs, when the engine fuelled by different fuel blends and diesel are shown in the Figure 3.4 above.

The BSEC of a blended fuel is the product of the BSFC and calorific value of the corresponding blend. The BSEC of diesel fuel varies from 10.7kJ/kWh at low load to 4.24kJ/kWh at full load. It can also be observed that the BSEC values for WPO diesel emulsions are 10.40kJ/kWh, and11.22kJ/kWh at no load and 11.22kJ/kWh, and 4.65kJ/kWh respectively. The energy consumption is higher in the case of emulsions because of this lower energy content.

Therefore the energy required to produce the same power output at the corresponding load is more than that of diesel operation. This behaviour is obvious since the engine will consume more fuel with Wood Pyrolysis Oil (WPO)-Diesel Fuel (DF) blends than Diesel Fuel, to gain the same power output owing to the lower calorific value of WPO-DF blends.

According to [4], in ethanol blend, brake specific energy consumption for the blends is higher than the diesel because ethanol has lower heating value. So increase in ethanol concentration unlike butanol, decreases heating value of the blend.

As shown in the 3-D surface chart of Fig 3.4, the optimum brake specific energy consumption across all blends of the fuel is of the range 0.04 – 0.06.

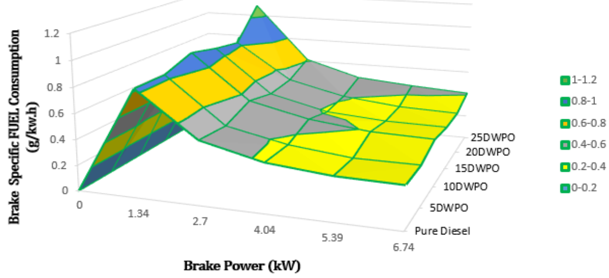

Figure 3.5: Variation of brake specific fuel consumption with brake power (*3-D Surface contour Modelling*)

Brake specific fuel consumption measures how efficiently an engine is using the fuel supplied to produce work. It is inversely proportional to thermal efficiency.

The rate of fuel consumption divided by the rate of power production is termed as brake specific fuel consumption. Brake specific fuel consumptions descend from lower to higher load level. It is related with brake thermal efficiency. At higher load conditions the brake thermal efficiency is increased and brake specific fuel consumption decreased.

When two different fuels are blended together the brake specific fuel consumption will not be more reliable because the calorific value and density of two fuels are different. The variations of the brake specific fuel consumption for the tested fuels are shown in Fig. 3.5, The research on diesel engine with blends of diesel-wood Pyrolysis oil shows that the BSFC was found to increase with load for

10DWPO, 20DWPO and diesel fuel. As the load increases, BSFC decreases for all fuel blends. At full load, WPO blends show the specific fuel consumption higher than the diesel. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads[6].

It could also be seen from the 3-D surface chart of fig 3.5 that the optimum brake specific fuel consumption across all blends of the fuel is of the range 0.2g/kW.h – 0.4g/kW.h

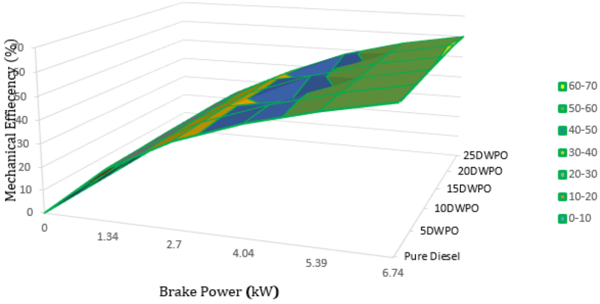

Figure 3.6: Variation of mechanical efficiency with brake power (*3-D Surface Contour Modelling*)

Mechanical efficiency measures the effectiveness of a machine in transforming the energy and power that is input to the device into an output force and movement. Efficiency is measured as a ratio of the measured performance to the performance of an ideal machine.

The mechanical efficiency of bio-biodiesel engines is higher at low loads and increases at high loads, compared to pure diesel oil engines. 20% blend of pyrolysis oil with diesel gives best result for the mechanical efficiency. It should be noted that similar behavior of result was obtained when ethanol is used as the ignition improver[5].

From Figure 3.6, it is clear that the mechanical efficiency of the engine increases with an increase in load under all operating conditions. On pure diesel mode at full load, the mechanical efficiency is found to be 58.9%. At full load, the mechanical efficiency is 59.96 % with 10%WPO and 60% with 20%WPO. This indicates that the engine produces more power as blend of the waste wood pyrolysis oil is increased.

Fig 3.6 reveals that the optimum mechanical efficiency across all blends of the fuel is of the range 60% – 70%.

4.0 Conclusion

Conclusively, the fast pyrolysis of biomass in the absence of oxygen has the potential to contribute to the world's need for liquid fuels and, ultimately, for chemicals production. Therefore waste pyrolysis oil should be used as an alternate source of fuel to the diesel in internal combustion engines or as an improver in the performance of pure diesel. Pyrolysis oil fuel compositions described herein in this research are suitable for use in internal combustion engines, including diesel engines of various configurations, as well as in equipment that combusts fuels to generate heat, such as furnaces, boilers, power generating equipment and the like, including gas or combustion turbines. Diesel engines that may be operated with compositions of the present invention include all compression-ignition engines for both mobile (including locomotive and marine) and stationary power plants.These include diesel engines of the two-stroke-per-cycle and four-stroke-per cycle types. The diesel engines include but are not limited to light and heavy duty diesel engines and on and off-highway engines, including new engines as well as in-use engines. The pyrolysis oil - diesel blend is recommended for use in machines where mechanical efficiency, brake specific energy consumption, exhaust gas temperature (as in furnaces) and brake specific fuel consumption are priority.

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