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WASTE VEGETABLE OIL AS AN ALTERNATIVE FUEL FOR DIESEL ENGINE

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ABSTRACT

Vegetable oils are emerging as promising fuel substitute to the conventional petroleum fuels from the view point of the energy crisis and emission problem. In this experiment waste vegetable oil is used as alternative fuel. Waste vegetable oil is used because it loose quality after being burnt several time. The waste vegetable oil's volatility and heat content is found to be lower but density and viscosity to be higher. Viscosity is considered as the main obstacles of using them directly as CI engine fuel. In the present study waste vegetable oil is preheated and blended with 20% diesel fuel and their effects on engine performance is investigated on a direct injection, 4 stroke, single cylinder diesel engine. Engine performance has been evaluated with the help of both conventional performance parameters and availability analysis. It is observed that the engine exhibits better results for higher preheating temperature and performance parameters become comparable with that of diesel when the preheating temperature reaches 80^{o}C. The performance parameters of the blend preheated to 100^{o}C become very close to that of diesel fuel. Exergy analysis shows similar result. Major portion of the fuel chemical availability is wasted in unaccounted factors and nearly 15% wasted with the exhaust gas which can be directly used for preheating.

Keywords: Waste vegetable oil, Engine performance, Exergy analysis

1. INTRODUCTION

The world depends mostly on petroleum based fuels but recent concerns over the environment, unstable price and depletion of reserves of petroleum fuels have prompted the interest for development of alternative sources of energy. According Bangladesh statistical year book 2008, Bangladesh spends about 4.5 billion U.S dollar equivalent to about taka 31 thousand crore as fuel bill for the last fiscal year. This is a huge amount for a country like Bangladesh. If this fuel bill could be reduced through discovery of any economically viable alternative fuel, the money thus spent could be used in development purposes.

The use of vegetable oils as an alternative fuel for diesel engines dates back to around a century. Due to rapid decline in crude oil reserves and increase in price, the use of vegetable oils is prompted again in many countries. Depending upon soil conditions, different nations are looking in different vegetable oils- for example, soybean oil in USA, rapeseed and sunflower oil in Europe, palm oil in Malaysia and Indonesia, coconut oil in Philippines are being considered to substitute diesel fuel [1].In the context of depleting food production and increasing human population there is very little scope to convert edible oil into fuel in Bangladesh. Lower volatility and higher viscosity of vegetable oils are the main impediments for possible problems encountered by the CI engines [2]. Viscosity of vegetable oil fuels can be reduced by at least four different ways: preheating, blending, microemulsionand transesterification [3] [4].Several investigations have been performed on bio- fuels of which most of them are concerned only on one type of modification technique to reduce viscosity and obtain the optimum point of that technique. Haq [5] has taken up attempts by studying different vegetable oil properties to use those as substitute of diesel fuel. Where kerosene was blended with 4 different vegetable oils (Rapeseed, Soyabean and Linseed) in equal volume to serve the purpose. Uddin [6] observed the behavior of SVO (Soyabean) with various performance parameters at different engine speeds and possibility of using as a substitute of diesel fuel. Morshed [7] carried out performance study of a direct injection, 4 stroke, 3 cylinder diesel engine by blending sesame oil with diesel. Where 80% sesame oil was blended with 20%diesel oil. Islam [8] carried out the performance test of diesel engine run by preheated straight vegetable oil on the basis of both the first and second laws of thermodynamics. Shaheed [9] observed mainly on the possible use of coconut-oil-based fuels as a substitute for diesel fuel. Diaz [10] has taken up attempts to prove that vegetable oil specially coconut oil is very clean fuel with excellent combustion properties.

None of these experiments were done for waste vegetable oil. In the present work, investigations were performed to explore the optimum technique and optimum point experimentally along with the exergy analysis. The main purpose of this work was to carry out an experiment whether different grades of WVO (waste vegetable oil) could be converted into economically viable fuel. According to WHO (World Health Organization), edible oil after being burnt several time loose quality for human consumption. Such type of oil could be converted into fuel to mitigate the short fall of fuel. For this reason waste vegetable oil two times fried was collected from restaurants, was then tested for its engine related properties.

The experimental works had been divided in two parts
a) fuel property testing and b) engine performance testing. Initially different properties (heating value, density, viscosity, flash point, distillation curve, carbon residue, ash content, water and sediment content) of diesel fuel were determined as base data. Those data were then compared with those of pre heated waste vegetable oil at different preheating temperatures, Waste vegetable oil and diesel fuel blends mixed at different proportions by volume and compare their properties with base data.

2. EXPERIMENTAL SETUP

A schematic diagram of the experimental set-up is shown in Fig. 1. Experiments are carried out using a 4 kW (6hp) single cylinder diesel engine of model R175A having a rated output is 4 kW at a rated speed of 2400 rpm. A water brake dynamometer has been used to apply desired load on the engine.

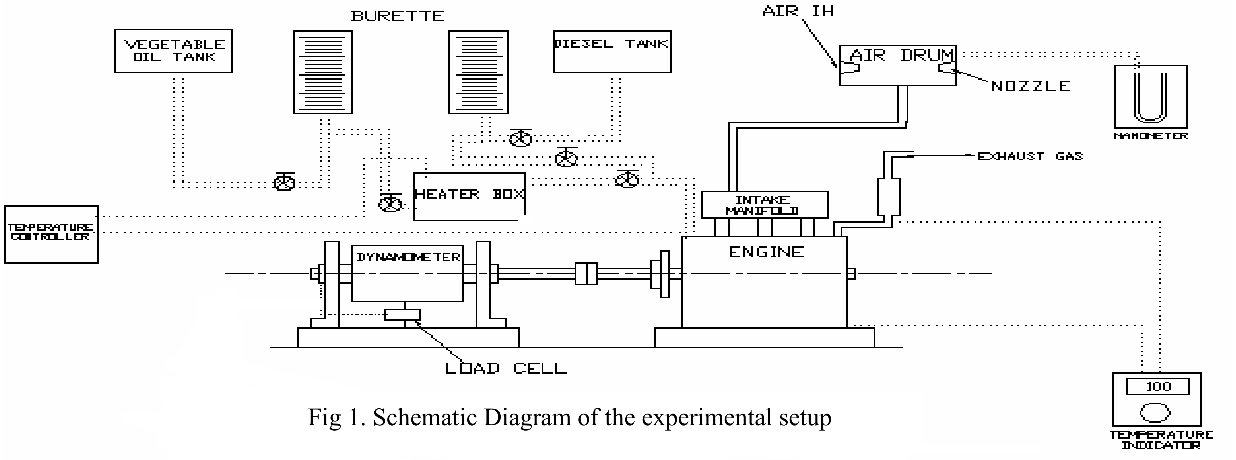

Fig 1. Schematic Diagram of the experimental setup

Initially the test engine is run by diesel fuel at three different speeds of 2400, 2200 and 2000 rpm and all the necessary parameters are recorded and different performance parameters are calculated to check the engine's credibility as a test engine. Then the performance tests are carried out using 100% waste vegetable oil preheated at 80^0C and 100^0C and 80% waste vegetable oil blended with 20% diesel preheated at 100^0C. Engine speed has been maintained within ± 5 rpm and the temperature was maintained within ± 2^0C of the desired temperature. In this study, BS standards for engine performance test BS 5514: Part I: 1982, equivalent to ISO 3046 and J 1349, ISO and SAE standards for the same respectively, has been followed.

Any other additional guidelines required were taken form the procedures used by Plint and Böswirth [11]

A water brake type dynamometer AN3e model is used to apply desired loads and to measure engine brake power. Lubricant temperature is measured using a thermocouple probe inserted into the lubricant oil sump. All temperatures are measured using digital meter (OMEGA-K), connected to different K-types probes via a selector switch. Diesel and waste vegetable oil supply systems have been modified, so that fuels could be supplied from a graduated burette instead of the fuel tank when needed. Fuel consumption rate is recorded observing the time by a stop watch for every 50cc of fuel. Air flow rate is measured by drawing air through two circular nozzles of 13 mm diameter (C_D = 0.92) in accordance with the Plint and Böswirth [11]with an air drum of standard size that is connected to the engine air inlet and pressure drop is measured by means of a manometer, using water as a manometric fluid. The mass flow rate of air is calculated by using the pressure drop in appropriate equation.

3. RESULTS AND DISCUSSION

In Fig. 2, variations of fuel densities with temperature are shown. It is found that waste vegetable oil density is 10% higher than that of diesel. When waste vegetable oil is blended with diesel and heated up to 100^{o}C, its density become less than that of diesel fuel at 20^{o}C.

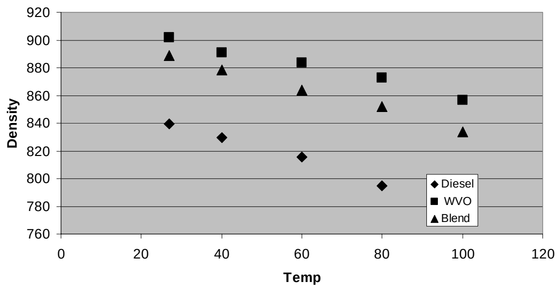

Fig 2. Variations of densities of oil with temperature.

In Fig. 3, viscosities of oils at different temperature are presented. It is seen that the viscosity of waste vegetable oil is nearly 10 times higher than that of diesel fuel at 20^{o}C but when waste vegetable oil is heated up then its viscosity reduces significantly and at 100^{o}C, viscosity of the both waste vegetable oil and its blend become less than that of diesel fuel at 20^{o}C.

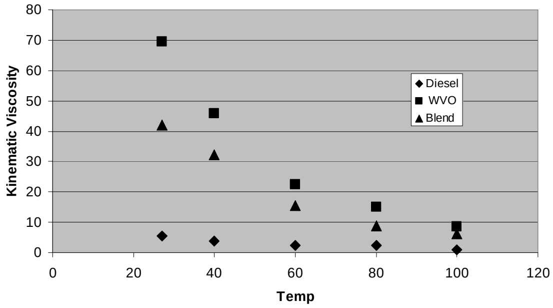

Fig 3. Effect of temperatures on the viscosities of fuels

Fig. 4 shoes the volatility of diesel and waste vegetable oil. It is seen that the volatility of waste vegetable oil is much lower than that of diesel fuel but the initial boiling of waste vegetable oil starts earlier than diesel fuel. T_{10}, T_{50} and T_{90} points on the curves are of special interest. Lower T_{10} temperature signifies easy starting and a lower T_{50} point allows the engine to warm up and gain power quickly and T_{90} temperature associated with crankcase dilution and fuel economy. If the T_{90} temperature is too high, the larger fuel molecules condense on the cylinder liners and is passed down into the lubricating oil instead of burning. With waste vegetable oil, T_{90} point is not achievable as chemical decomposition of the fatty acids start before reaching that point.

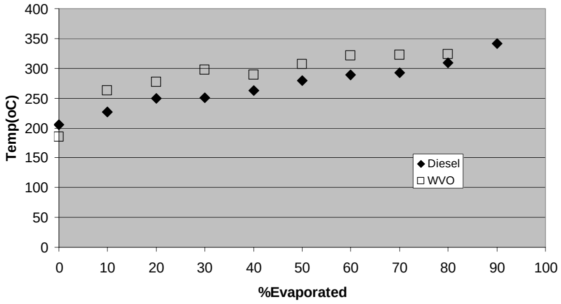

Fig 4. Distillation curves

In order to judge the potentiality of using waste vegetable oil as an alternative to diesel fuel, the experiments are carried out at three different speeds (2400, 2200, and 2000) under variable loading condition using diesel fuel. It is seen that for the same output power, air flow rate increases with engine speed due to the fact that the swept volume per unit time is higher for higher engine speed. Air induction of engine depends on the ratio of intake and exhaust pressures, residual gas volume, intake air velocity, engine speed, size and shape of the passages. Residual gas fraction effect is less in CI engine due to higher compression pressure. As the gas velocity increase pressure drop also increase and breathing reduces. Again, at higher engine speed, intake system or a part of the intake system is chocked and once this occurs, further increase in speed does not increase the flow rate significantly and so, volumetric efficiency, η_v decreases. Again at higher speed, air flow rate per cycle decreases due to short cycle time.

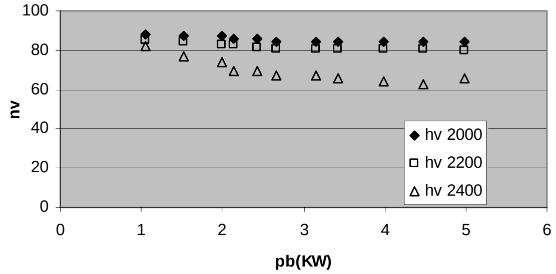

Fig 5. Variation of volumetric efficiency with engine brake power run by diesel

In diesel engine, higher power is achieved by increasing the fuel flow rate. Also, the fuel consumption rate increases with speed. With increase of speed the frictional loss increases and to overcome that more power required inside the cylinder and so, fuel flow rate increases with speed. At part load, more fuel is consumed for higher engine speed but near the rated power, the engine consumes almost the same amount of fuel to generate the same amount of power for all three speeds. This behavior is directly related to friction. Engine friction is either related to engine speed or to peak engine cylinder pressure. At low loading condition the effect of engine cylinder pressure is insignificant and frictional losses are dictated by the energy consumed by the shafts, valves and pumps. These losses increase with the speed of the engine. So, at low loading conditions fuel consumption is higher at higher speed. However, at higher load, the effect of peak cylinder pressure becomes more significant. For the same power output, slower speed generates more pressure and frictional loss increases and so, at higher loading fuel consumption rates become almost the same for all the three speeds.

Stoichiometric combustion of diesel fuel requires 14.30 A/F ratio but from experiment it is seen that the air fuel ratio at low load is nearly 55. With the increase of load, A/F ratio reduces and up to 45% of the rated power it reduces steeply. The falling trend continues over the entire range but a lower rate. In CI engine, output power is increased by increasing the fuel flow rate and at the same time the air flow rate decreases with the increase of load which has already been mentioned. A 'cross over' point is observed almost at the middle of brake power P_b Variations of brake specific fuel consumption, *bsfc* with P_b at different speed is shown in Fig.6. It is seen that *bsfc* is high at low loads and its value decreases with the increase of brake power until the rated output of the engine is reached. Beyond that the value increases again. At lower load, A/F ratio is much leaner. Also that the residual gas temperature and wall temperature is lower and ignition delay period is higher and so, fuel utilization efficiency is less. So, *bsfc* value is higher at lower load again at higher load beyond the rated point all the fuel is not burned properly due to scarcity of air. Energy input in the fuel is lost in the form of incomplete combustion that results in higher *bsfc*.

It is also observed that, for the same output power, at part load condition *bsfc* is higher for the higher rpm but at rated or higher than rated rpm *bsfc* is independent of speed. The main reason here is the friction which has been already mentioned earlier.

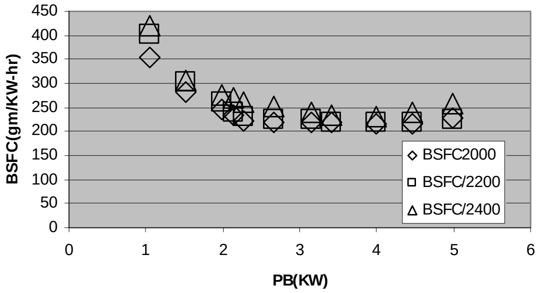

Fig 6. Variations of brake specific fuel consumption with brake power run by diesel fuel

The *bsfc* is a measure of overall engine efficiency, η_b and these quantities are inversely related. So, that lower the values of *bsfc* higher the overall efficiency of the engine. However ,for different fuels with different heating values, the *bsfc*'s values are misleading and hence brake thermal efficiency is employed when the engines are fueled with different types of fuels [5]. In Fig.7 brake thermal efficiency, η_b is plotted against the brake power, P_b for different speeds

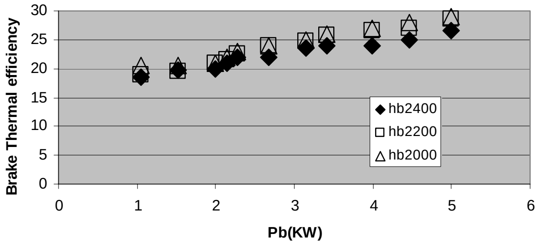

Fig 7. Variations of brake thermal efficiency with engine brake power run by diesel fuel.

The brake thermal efficiency, η_b of the test engine is plotted against brake mean effective pressure (*bmep*) in Fig. 8. Engine performance parameters presented as a function of engine brake power is unique for a particular engine at a particular speed. The performance curves for engines of different sizes or for the same engine at different speeds derivates far from each other.

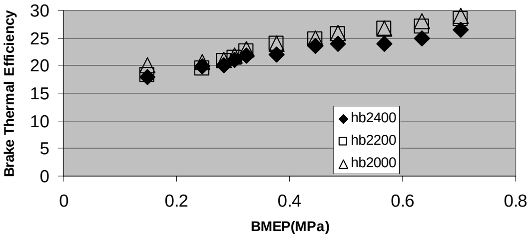

Fig 8. Variations of brake thermal efficiency with brake mean effective pressure run by diesel fuel.

The availability (or exergy) input to an internal combustion engine is contained in its fuel chemical availability. In CI engines, the input availability contained in fuel is converted into: 1.useful brake output availability 2.availability transferred to cooling medium 3.availability transferred to exhaust gases 4.availability destroyed in engines accessories turbocharger, cooling fan, etc. and 5.availability destroyed due to friction and radiation heat loss to surroundings. Szargurt and Styrylska [12] developed the following correlation for computing the chemical availability of liquid hydrocarbons having the general formula $C_xH_yO_zS_w$:

$$A_{in} = Q_{in}\left[1.0374 + 0.0159\frac{y}{x} + 0.0567\frac{z}{x} + 0.5985\frac{w}{x}\left(1 - 0.1737\frac{y}{x}\right)\right] \quad (1)$$

For diesel fuel, $A_{in} = 1.06489\ Q_{in}$, For waste vegetable oil, $A_{in} = 1.0724\ Q_{in}$. In the present analysis, due to scarcity of thermo chemical data (specially for waste vegetable oil) 'percent brake output availability', A_{shaft} is used in lieu of second law efficiency, η_{II}. The availability is destroyed or lost due to different irreversibility such as combustion losses, friction losses, heat loss to lubricating oil, power consumed by auxiliary equipment (axial blower in the present test engine), radiation losses, fluid flow losses, etc. Availability transfer to cooling medium (water in this case) has been included into the above category. Availability destruction due to all these sources are combinedly expressed by $A_{uncounted}$. This is justified by the fact that availability transfer to cooling medium in an water-cooled engine is only a fraction (less than 2.5%) of the availability input to the engine [13]. Availability destroyed in the exhaust gas is evaluated separately.

In Fig.9, the portion of the input availability converted into brake output power denoted by A_{shaft} is shown. It may be noted from this figure that at higher *bmep*, availability output show a slightly declining trend after the rated output

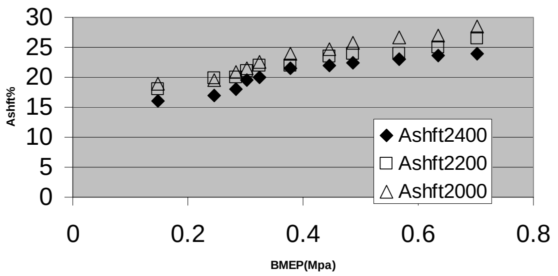

Fig 9. Variations of percent availability output at shaft with engine brake mean effective pressure run by diesel fuel.

The availability input lost in different processes of the engine is shown in Fig. 10. It may be seen that the availability transfer to the exhaust gases (denoted by A_{eg}) increases with increasing *bmep*, which is quite a small portion of the availability input, the maximum level having reached approximately 12% of A_{in}. In contrast, the availability destruction in friction, cooling, combustion etc. (denoted by $A_{uncounted}$) shows a declining trend. That is, with the increase in *bmep* as A_{eg} goes up $A_{uncounted}$ continues to go down although its extent is far greater. However, the opposite trends of these lines facilitate finding an ‘optimum operating point’ from the graph. The optimum operating point is around 0.45 MPa

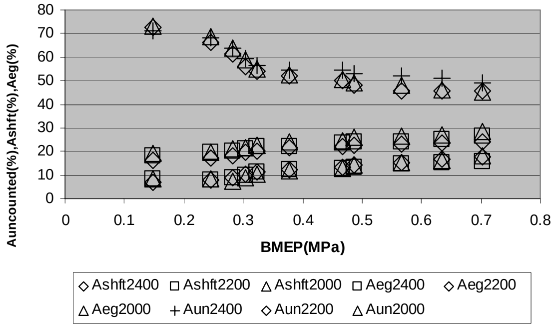

Fig 10. Level of different types of availabilities associated with engine operation as a function of brake mean effective pressure run by diesel fuel.

The comparison of η_b with A_{shaft} is shown in Fig. 11 to obtain a precise contrast of the two, the curves are plotted at the same plane for a rated speed of 2400 rpm. Observation reveals that A_{shaft} is somewhat less than η_b throughout the entire range. Both the graphs substantiate the fact that the capability of an engine to utilize the available energy successfully is rather less than that articulated in brake thermal efficiencies. The major reason behind this is that the fuel chemical availability, A_{in} is about 3.35 to 7.25% as higher (depending on the chemical formula of the fuel) than the heat input Q_{in} calculated from the lower heating value and this available energy can not be interpreted into shaft work due to inherent irreversiblities.

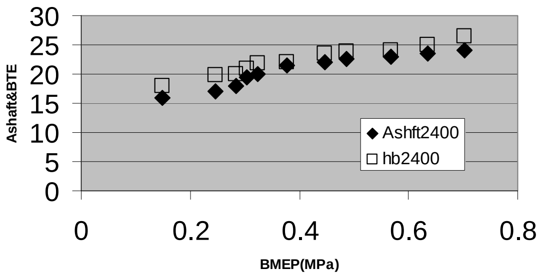

Fig 11. Comparison of percent availability output at shaft with corresponding brake thermal efficiency as a function of brake mean effective pressure run by diesel fuel at 2400 rpm.

Fig. 12, shows the variations of brake specific fuel consumption as a function of brake power for two different preheat temperature 80 °C and 100 °C of waste vegetable oil as well as for 80% waste vegetable oil and 20% diesel blend preheated to 100 °C is compared with that of diesel fuel. From this figure, it is evident that, the specific fuel consumption is higher in the case of vegetable oils. Vegetable oil’s heating value is much lower than that of diesel fuel. Again high viscosity and poor volatility of the waste vegetable oil result in poor atomization and mixture formation which, in turn, increase the fuel consumption to maintain the power.

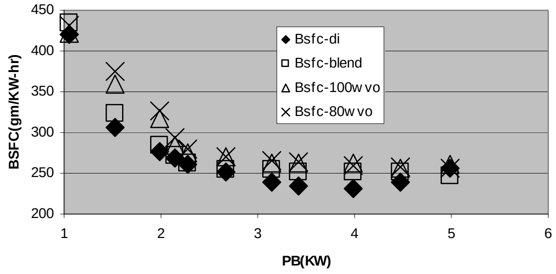

Fig 12. Comparison of the bsfc of different fuels at 2400 rpm as a function of brake power.

With the increase of preheat temperature viscosity of oil greatly reduces to help better fuel injection, atomization and mixing quality of the charge and so, fuel consumption rate decreases. But at high load the temperature effect becomes less significant. At higher load, fuel flow rate and velocity are dominated by the combustion temperature and hence fuels arrive at the point of injection of any preheated temperature with about the same temperature, providing similar injection conditions. Again a blend of 20% diesel and 80% waste vegetable oil preheated to 100°C does not increase the efficiency over 100°C preheated waste vegetable oil. It may be due to the fact that at that temperature extra fine spray formation occurs which reduces penetration and mixing with air offsets the decrease of consumption of fuel.

In Fig. 13, a variation of brake thermal efficiency is shown for the above mentioned conditions. It is seen that the brake thermal efficiency of diesel fuel is lower than that for the waste vegetable oil and the blend preheated at

100^oC. Vegetable oil’s ignition delay period is also longer than diesel and so, pressure rise inside the cylinder is lower and the frictional loss due to pressure is also less.

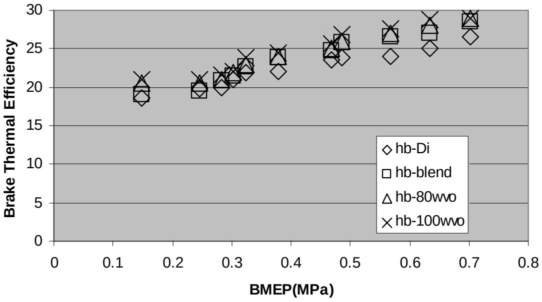

Fig 13. Comparison of the brake thermal efficiency of different fuels at particular speed as a function of brake mean effective pressure.

Brake thermal efficiency as a function of engine brake power is plotted in Fig. 14. The trend of the curve is similar but from the figure it is clear that some power losses are experienced for fuels other than diesel. For each case, the highest efficiency is observed at lower rpm. Ignition delay period is much higher for waste vegetable oil and so, at higher speed fuel gets less time for heat release or heat release occurs late in the expansion stroke and so, effective use of heat becomes less.

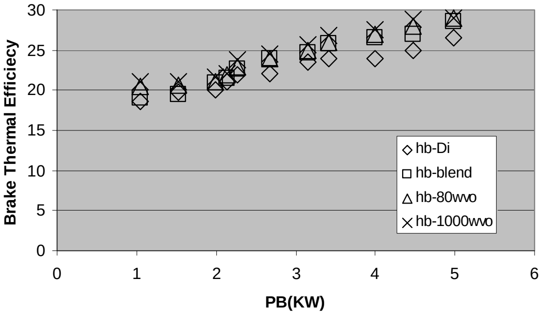

Fig 14. Variations of brake thermal efficiency for 2400 rpm at varying loads for a particular fuel.

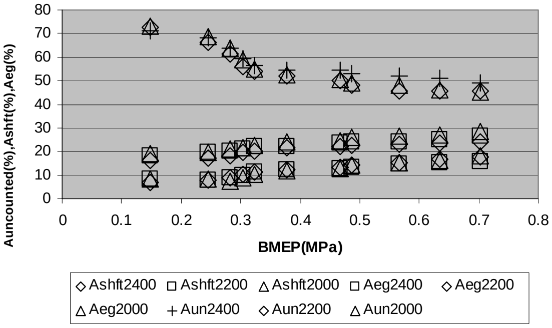

Fig 15. Variations of percent available at shaft and destruction of availability as a function of brake mean effective pressure running by 100^0C waste vegetable oil and diesel blend.

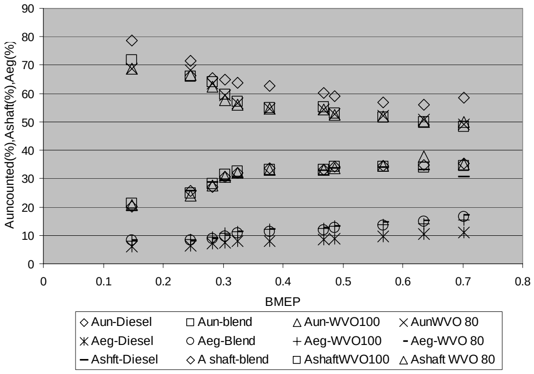

Fig 16. Variations of percent available at shaft and destruction of availability as a function of brake mean effective pressure running for 2400 rpm.

4. CONCLUSION

The obtained results may be summarized to make the following conclusions:

(1) Without preheating, waste vegetable oil can not be used directly.
(2) Compared to diesel fuel operation, a little amount of power loss occurs with waste vegetable oil operation.
(3) Fuel consumption becomes similar for heated and unheated oil operations at higher load.
(4) At lower rpm operation waste vegetable oil exhibits better results for any preheat temperature.
(5) The heating energy of waste vegetable oil is almost the same as that of diesel when preheating temperature is 80^oC or more than that.
(6) Preheating the blend of waste vegetable oil with 20% diesel fuel exhibits almost the same result when waste vegetable oil is preheated to the same temperature.
(7) Availability destroyed with exhaust gas increases with load and is about 15% of the input availability at rated condition. This may be used directly for preheating purpose.
(8) Major portion of the available energy is lost due to friction, cooling, combustion etc., which is mentioned here as uncounted factors. So, for engine performance improvement much focus required here.

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