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POWER PERFORMANCE UNDER CONSTANT SPEED TEST WITH PALM OIL BIODIESEL AND ITS BLENDS WITH DIESEL

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ABSTRACT

The torque and power performance tests were carried out with a single cylinder techno four-stroke diesel engine under constant speeds of 2000, 1500 and 1100rpm. Five fuels, the Dura Palm Oil biodiesel, B_1100; Tenera Palm oil biodiesel, B_2100; Dura Palm Oil biodiesel/diesel blend at 10/90 vol/vol, B_110; Tenera Palm oil biodiesel/diesel blend at 10/90 vol/vol, B_210 and the diesel or Automotive gas oil (ago), the reference fuel, were involved. Brake torque and brake power data were plotted against brake mean effective pressure (Bmep) since the latter is independent of engine speed and size and it is an indication of how power and torque are obtained per litre of fuel. The curves for the torque versus Bmep for the five fuels merged into a single straight line curve which extended to the origin and with a gradient of 0.0719m^3 for all the three speed tests of 2000, 1500 and 1100rpm. Similarly, the power versus Bmep curves for the five fuels merged into one straight curve which also extended to the origin but with different gradients of 0.0151, 0.0113, 0.0083 for 2000, 1500 and 1100rpm respectively. Therefore, the five fuels had similar torque and power performance characteristics in the engine. The straight line curve which can be extrapolated to any value can be used for the engine designs, that is determining v_d from the relation, $T = V/4$ or $B_p = V_dN/2$

Keywords: Dura Palm Oil/biodiesel, Tenera Palm Oil biodiesel, torque, power, brake mean effective pressure.

1.0 INTRODUCTION:

The present scarcity of petroleum fuels has challenged many researchers to look for alternative sources, which may even be environment friendly, unlike the conventional fossil fuels. This has led to the development of biofuels in the form of the biodiesel and the bioethanol for the diesel and petrol engines respectively.

There is a particular interest in biodiesel, a diesel fuel replacement, because of the importance of diesel in Gaps are measured in time and are equal to headways. Agricultural, Industrial and transport sectors of the economy. Much work has been done in the development of this biofuel which is derived from vegetable oil. Engine tests have been carried out to ascertain its performance in the diesel engine.

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The results show that it has similar performance characteristics as petroleum diesel.
During such tests, Reece and Peterson (1993) observed reduction in power ranging from 1 to 7%. But Feldman and Peterson (1992) observed increase in power during a 200h engine test. Many researchers had observed slightly higher fuel consumption in biodiesels than in petroleum diesel. Thermal efficiencies were also reported to be higher in biodiesels than in diesel (Quick, 1989).

Schumacher, et a., (1994); and Nwafor (2001), observed that fueling with biodiesel/diesel fuel blends effectively reduced particulate matter (PM), unburned hydrocarbon (HC) and carbon monoxide (CO), while increasing oxides of nitrogen (NOx) emission. Schumacher (1994) also observed that the optimum blend, based on the trade-off PM decrease and NOx increase was a 20/80 biodiesel/diesel fuel blend.

Schumacher, et al (2005), observed that replacing the diesel fuel with biodiesel reduced the wear of aluminum, iron, chromium and lead components in a diesel engine. They also saw that the amount of wear in metals found in the lubricating oil of rapeseed derived biodiesel driven engine was not statistically different from the amount found in soybean derived biodiesel driven engine lubricating oil samples. Masjuki, et al (1993), investigating the performance of palm oil diesel (methyl ester of crude palm oil) noted that the highest level of iron from the lubricating oil analysis came from pure conventional diesel.

They also found that as the percentage of the palm oil diesel (POD) increased in the fuel blend, the iron level decreased throughout the test period. Diesel.Ituen (2009), observed that carbon monoxide (CO) emission was reduced more than 60% by blending Dura palm oil biodiesel with diesel at 20/80 vol./vol biodiesel/diesel under constant load test condition. Ituen, et al., (2009), showed that with the use of Dura palm oil biodiesel, the mechanical efficiency of a diesel engine was by far higher than that of Diesel and Tenera palm oil biodiesel, under constant speed condition.

Although Nigeria is blessed with much of petroleum resources, the reserve is fast depleting and will one day be exhausted, and the country may run into serious energy crises. There is need to begin to look into alternative and renewable sources of energy. The biofuel development is highly recommended for this especially as it is of direct energy use, mostly needed in the farms and industry. In times of fuel crisis, farmers can use biodiesel for continuous food production.

Again, there is a lot of environmental pollution caused by emissions coming from the very large number of motor vehicles and other forms of internal combustion engines in the country. Blending biofuels with conventional fuels reduce these emissions which are said to account for about 70% of the atmospheric carbon (Cheremisinoff, 1989).

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Biodiesel development will promote fuel blending and hence cut emissions from vehicles and electricity generating plants which are causing a lot of health hazards and even deaths in Nigeria. The reduced emissions will also help to bring down the current climate change which is a cause of concern globally.

The oil palm, which is a major source of vegetable oil is in abundance in Nigeria and it is a good feedstock for biodiesel production. This plant is the highest oil bearing crop plant in the world, capable of producing 5 to 7 tones of palm oil per hectare (Gascon, et al., 1989). It can produce continuously for more than 100 years once it is planted. For this reason, it has advantages over other oil bearing plants, many which are annuals and require a lot of energy and resources for repeated cultivation. With the present efforts of governments and the private sector in establishing new plantations of high yielding variety (the Tenera), there are potentials for increased palm oil production which may enhance large scale production of biodiesel. The wild variety, the Dura, is Being phased out and replaced with this improved variety.

However, the Dura still constitutes about 65% of the groves, especially in the original oil palm belt of Eastern Nigeria. Its oil is often preferred to that of Tenera by farmers because it is less viscous; it was brought into this work to explore its potential for fuel energy before it becomes extinct. Much work in energy has not been Done on this variety.

This paper presents the investigation of the performance of palm oil biodiesel in the diesel engine, especially with regard to Torque and power output under constant speed. The biodiesel was produced by a chemical process called transesterification from palm oil obtained from both the Dura and Tenera varieties of the oil palm.

2.0 THEORETICAL CONSIDERATIONS

2.1 Torque Measurement

Torque is a good indicator of an engine's ability to do work.. It is related to work as shown by Pulkrabek (1997), by:

$$2T = w_b = (Bmep)\, v_d/n \qquad (1)$$

where w_b = brake work of one revolution of the shaft, KJ

T = torque, N-m

v_d = displacement volume, m^3

n = number of revolutions per cycle = N/60

N = engine speed, rpm.

Pro Bmep = brake mean effective pressure, KN/m^2

For a 4stroke cycle engine, with 2 revs/cycle, n=2

then, $T = (Bmep)\ vd/4 \qquad (2)$

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Since torque is a measure of the output at the crankshaft, it is portional to the brake mean effective pressure (Bmep) and brake work (w_b) as seen in equations (1) and (2) with the same engine. Torque varies directly with Bmep.

2.2 Power Measurement

Brake power is given by the relation,

$$B_p = 2\pi NT = w_b N \quad (3)$$

where

B_p = brake power, kW
N = engine speed, rpm
T = torque, N-m
w_b = brake net cycle work, kJ.

From equation (1), equation (3) can be written as

$$B_p = (Bmep)\, v_d N/2 \quad (4)$$

With the same engine, brake power, B_p varies with both the brake mean effective pressure (Bmep) and the engine speed, N

Equation (4) can be written as

$$B_p = p_b lan \quad (5)$$

where p_b = Bmep, kN/m^2
la = v_d, m^3
N = N/2, for a 4-stroke cycle engine.

3.0 EXPERIMENTAL PROCEDURE

Biodiesel was produced from both the Dura and Tenera palm oil by a chemical process called transesterification. Palm oil was reacted with alcohol (methanol) in the presence of a catalyst (Sodium hydroxide) to produce glycerin and methyl alkyl ester or biodiesel in a batch reactor, which was stirred for 2½hrs at 980 rpm. The biodiesel so produced is alkaline and was decanted and washed in water until the PH was 7.00 and the fuel became neutral. It was then dried by heating and cooled for use.

The engine performance was conducted at constant speeds of 2000, 1500 and 1100rpm with a single cylinder techno four-stroke water-cooled diesel engine. The speeds were chosen to investigate the performance at high load (wide open throttle-WOT), medium load or cruising speed and low load (low speed). The techno diesel engine of model no. S1100Nm was chosen because it is a modern diesel engine which is built to accommodate biodiesel too as a fuel.

Fuel measurement was by gravity with a 50ml burette and a stop watch. The fuel tanks for diesel and biodiesel were raised to the same height as the maximum level of fuel in the burette for gravity feeding. Time for the consumption of a fixed volume (40ml) was recorded. The engine was fed by a two-way valve line which enabled rapid changing from the reference diesel fuel (Automative gas oil) to the candidate fuels. The candidate fuels included 100 percent Dura palm oil biodiesel ($B_1$100); 100

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percent Tenera palm oil biodiesel ($B_2$100); 10/90 vol/vol Dura palm oil biodiesel/diesel blend ($B_1$10); 10/90 vol/vol Tenera palm oil biodiesel/diesel blend ($B_2$10). The engine speed was measured by a digital tachometer. The load measurement was by a prony brake dynamomenter designed and constructed for this work.

Equipment:

Engine Data:

Cylinder bore	100mm
Stoke	115mm
Piston displacement/engine capacity:	0.903 litres
Compression ratio:	20
Max. rated Engine speed:	2200rpm
Max. Power output:	11.63kW
Over burden rated output:	12.13kW
Type of starting: Cranking/starter	
Fuel injection timing:	18° ± 1°
Bmep:	697kPa
Specification consumption: not greater than250.2g/kWh	

4.0 RESULTS AND DISCUSSION

Data generated from this work for the high speed of 2000rpm are presented in Tables 1 to 5. Those for 1500 and 1100rpm take the same pattern although they are not presented. The data were used in plotting the curves in Figures 1 to 6. Figures 1 to 3 show the computer generated plots of Torque (T) versus Brake mean effective pressure (Bmep) for 2000, 1500 and 1100rpm respectively. Figures 4 to 6 show the plots of power against brake mean effective pressure for the same three speeds. The plots are against Bmep because Bmep is independent of speed and size of the engine and it is a clear indication of how power and torque are obtained per liter of fuel (Pulkrabek, 1997).

4.1 Torque Versus BmepPerformance

All the curves of the five fuels in the 3 speeds tested merged into one straight line curve which tended towards the origin, indicating perfect proportionality between the torque and brake mean effective pressure. The R^2 (correlation coefficient) value of 1 for all the curves also support this assertion. The single straight line curve shows that all the five fuels produced the same torque from an equal brake mean effective pressure. This relation between torque and Bmep can be investigated. Torque is related to work as in equation (1). To plot T against Bmep, then $V_d/4$ becomes the gradient of the curve. For a particular engine, V_d is a constant and hence the gradient, $V_d/4$ is a constant. This shows why the gradient for the curves for the 3 speeds is the same for the same engine. Therefore the torque of an engine may not increase significantly with increase in speed, but certainly decreases at high speeds mainly due to friction and heat losses (Pulkrabek, 1997). For the speeds chosen, the torques are almost the same. This is shown by the computer generated equations which follow:

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Using diesel, the valve for torque in the three speeds are given by their respective correlation equations as

$T_{2000\,rpm}$ = 0.0719 Bmep 0 0.0001

$T_{1500rpm}$ = 0.0719 Bmep 0.0002

$T_{1100rpm}$ = 0.0719Bmep - 0.0472

If the same valve of Bmep is assumed for the three speeds equations shown above, the torque will be almost the same. This is why the torque versus speed curve in a constant speed test gives almost a flat curve (constant torque) and will only decrease sharply at very high speed due to friction and heat losses as stated earlier. This pattern is the same for the other candidate fuels.

Investigating with the engine used for the test, V_d = 0.903 litres = $0.903 \times 10^{-3} m^3$

Bmep is in KN/m^2

and T = N-m.

Therefore the relation is T = 1000 (Bmep) $V_d/4$

The gradient = $1000V_d/4$ = 10^3 $(0.903 \times 10^{-3})/4 = 0.07186m^3$

This is the same as the computer generated gradient of the curves for that engine shown in Figures 1 to 3.

Although the torque value was almost the same with the same Bmep for the five fuels, yet there were very insignificant differences as indicated by the intercept of the curve on the y-axis at about the origin. With the speed of 2000rpm(Figure 1), all the intercepts are shown to be

With the 1500rpm speed (Figure 2), all the biodiesels and their blends had positive intercepts while the diesel had a negative valve. This shows that the four candidate fuels performed better than diesel. At the very low speed of 1100rpm, (Figure 3) the two pure biodiesels, the Dura and Tenera, had positive intercept values while diesel and the blends had negative values. The Dura biodiesel performed the best. The torque versus Bmep curve can be extrapolated to any value. The torque and corresponding Bmep values can be used to determine the V_d value for an engine design.

Again, the plot of power versus Bmep for the five fuels merged into one straight line as it was with the torque versus Bmep.

The relationship of the curve can be written as in equation (4), B_p= (Bmep) $V_d N/2$

For a particular speed, constant speed, the gradient of the curve, $K= V_d N/2$

For the change in speed, N, the gradient changes. This is why the gradients of the curves for the 3 engine speeds are different.

For N = 2000rpm (figure 4)

$$K = \frac{0.903 \times 10^{-3} \times 2000/60}{2} = 0.01505m^3$$

for N = 1500rpm (figure 5)

$$K = \frac{0.903 \times 10^{-3} \times 1500/60}{2} = 0.011287m^3$$

For N = 1100rpm (figure 6)

$$K = \frac{0.903 \times 10^{-3} \times 1100/60}{2} = 0.008275m^3$$

These K values calculated agree with the computer generated gradients of the curves of the 3 speeds in Figures 4 to 6.

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Using diesel fuel again, the value of the brake power, B_p can be calculated from the computer generated correction equations shown as follows:

$$B_{p2000rpm} = 0.0150\,Bmep + 0.0004$$

$$B_{p1500rpm} = 0.0113\,Bmep + 0.0002$$

$$B_{p1100rpm} = 0.00083\,Bmep + 0002$$

The above expressions show that the values of Brake power will increase with increase in speed until at very high speeds when it will drop sharply due to friction and heat losses (Pulkrabek, 1997).

Generally, the single line curve for all the five fuels in the test indicates that they developed equal torque (Figures 1 to 3) and power (Figures 4 to 6) for the same brake mean effective pressure. Since a single cylinder engine was used, the same displacement volume, V_d was used for all the fuels. In the cylinder, when the heating value of fuel is less as in pure biodiesel as compared with diesel, more fuel is consumed to produce the same torque or power (Tables 1 to 3). The heating value of diesel was 41, 478.3 kJ/kg while that Dura biodiesel was 38, 131.0 kJ/kg. The increased fuel flow rate offsets the reduced heat content of the biodiesel. This agrees with the works of Gascon et al. (1989). However, the blends Dura (B_110) and Tenera (B_210) surprisingly had very high heats of combustion as compared with diesel. Their values were 41,217.4 kJ/kg and 41, 978.27 kJ/kg (Ituen, 2007). This phenomenon is reflected in Tables 4 to 5 where the fuel consumption (kg/h) for the two blended fuels are lower than those of diesel and the two pure biodiesel, B_1100 and B_2100 (Tables 1 to 3)

The blends at 20 vol/vol Dura/diesel and Tenera/diesel had much more heat of combustion than diesel. The superiority of these blends over the unblended fuels of diesel, and the two pure biodiesels is further shown by their fuel economy, exhibited by lower brake specific fuel consumption (Tables 4 to 5). This uncommon behaviour of the blends at 20/80 vol/vol biodiesel/fuel was investigated and it was observed that the temperature of the Dura blend dropped more than that of pure biodiesel and pure diesel differently. This indicated endothermic reaction which may result in stronger bonding and hence higher heat of combustion.

The single straight-line curve also shows that the fuels have similar behavioural pattern (Figures 1 to 6). Therefore biodiesels and their blends with diesel can be adapted to existing diesel engines without engine modifications. It was seen that the Dura palm oil biodiesel performed extremely well in the test. The Dura palm oil biodiesel had no hard starting even when the engine was left for more than one week in cold weather (harmattan), unlike the Tenera palm oil biodiesel which had hard starting and so needed warm up and cool down activities (Ituen, 2007). Its cetane number was highest, with 51.12 as against diesel with 45.70.

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5.0 CONCLUSION

The plots of brake torque against brake mean effective pressure showed that the curves of all the five fuels merged into one straight curve which passed through about the origin. The correlation coefficient (R^2) for all the curves was I, showing perfect linearity and perfect proportionality between torque and brake mean effective pressure under constant speed tests. The straight line curve was obtained in all the three constant speeds of 2000, 1500 and 1100rpm, which incidentally had the same gradient. The gradient was not affected by change in speed.

In the plots of brake power against brake mean effective pressure, the curves of the five fuels also merged into one straight curve, which passed about the origin. The correlation coefficient for all the curves was one. This also showed that the brake power was directly proportional to the brake mean effective pressure under constant speed condition. However, the gradients for the curves of the three speeds were different showing that change in speed affects the brake power in a constant speed test. Brake power increased with increase in speed.

The straight line curve, indicating merger of the curves of the five fuels shows that biodiesel and its blends with diesel, have the same characteristics with diesel. Hence, they can be used in diesel engines without modifications.

Biodiesels, when properly purified, are neutral and so will not attack even the rubber parts of the engine. Biodiesels are environment- friendly. They are blended with diesel to cut down emissions. Biodiesel will help in times of fuel scarcity. Farmers can rely on it for timely farm operations. Petroleum oil will one day dry up. Biodiesel development may be very helpful as alternative and renewable energy source in such a time.

REFERENCES

Cheremisinof, F. N. (ed). 1989. Encyclopedia of Environmental Control Technology, Vol.2. Air pollution control. Gulf publishing Company, Book Division, Houston, Texas.

Feldman, M. E. and C. L. Peterson. 1992. Fuel injection timing and pressure optimization on a D1 diesel engine for operation on biodiesel liquid fuels from renewable sources proceedings of an Alternative Energy Conference, Nashville, JN.

Gascon, J. P.; J. M. Noiret, and J. Meuiuer. 1989. Oil palm, in the oil crops of the world; McGraw-Hill publishing Co., New York. 475-493.

Ituen, E. U. U. 2007. Production and Performance evaluation of palm oil biodiesel in a diesel engine. Unpublished Ph.D. thesis, Department of Agricultural Engineering Federal University of Technology, Nigeria.

Ituen, E. U. U. 2009. Carbon monoxide (CO) Emissions reduced with palm oil biodiesel. Global Journal of Engineering and Technology. 2(2): 271-275.

ISSN: 0189-9546
Faculty of Engineering & Technology University of Ilorin, Ilorin, Nigeria.

Ituen, E. U. U.; C. I. Ijioma and O. M. I. Nwafor 2009. Mechanical Efficiency of
diesel engine operating on palm oil biodiesel at high load under constant speed. International journal of Engineering, 3(2): 179-186.

Masjuki, J; A. M. Zaki, and S. M. Sapuan. 1993. Methyl ester of palm oil as an
alternative diesel fuel. In proc. Annual conf. of combustion engine group of the institution of mechanical engineering, London.

Nwafor, O. M. I. 2001. Emission characteristics of neat rapeseed oil fuel in
diesel engine. International journal of ambient energy. 22(3): 146-154.

Pulkrabek, W. W. 1997. Engineering fundamentals of the internal combustion
engine (1 ed). Prentice-Hill Inc. New Jersey.

Quick, G. R. 1989. Oil seeds as energy crops, in the oil crops of the world;
McGraw-Hill publishing Co., New York, Sydres, Tokyo. (118-131).

Reece, D. L. and C. L. Peterson. 1993. A report on the Idaho on-road vehicle
test with RME and neat rapeseed oil as alternative to diesel fuel. ASAE paper No. 93-5018. ASAE. St. Joseph MI.

Schumacher, L. G.; S. C. Borgelt, W. G. Hires, D. Fossen, and W. G. Goetz. 1994. Fueling diesel engines with blends of methyl ester of soybean oil and diesel fuel. Biodiesel 94. Sionx falls. SD.

Schumacher, L. G.; Charles L. Peterson, J. Van Gerpen. 2005. Engine oil
Analysis of Biodiesel-fueled engines. Applied Engineering in Agriculture. 21(2): 153-158. ASAE.

Table 1: Results of constant speed test at 2000rpm (Diesel)

Load $(T_1-T_2)g$(N)	Fuel Consumption (kg/h)	Torque (T1-T2)r (N-m)	Brake Power (kW)	Brake m.eff.pr. (kN/m2)	Brake sp.F.c. (kg/kW-h)
88.29	1.207	11.21	2.348	156.00	0.514
98.10	1.339	12.46	2.610	173.40	0.513
127.53	1.480	16.20	3.393	225.44	0.436
137.34	1.496	17.44	3.653	242.70	0.410
156.96	1.596	19.93	4.174	277.35	0.382
196.20	1.640	24.92	5.219	346.79	0.314
206.01	1.724	26.16	5.479	364.05	0.315
215.82	1.746	27.41	5.741	381.44	0.304
230.30	1.981	29.25	6.126	407.05	0.323

Table 2: Results of constant speed test at 2000rpm (Dura palm oil biodiesel)

Load $(T_1-T_2)g$(N)	Fuel Consumption (kg/h)	Torque (T1-T2)r (N-m)	Brake Power (kW)	Brake m.eff.pr. (kN/m2)	Brake sp.F.c. (kg/kW-h)
78 .48	1.278	9.97	2.088	138.74	0.612
98 .10	1.495	12.46	2.610	173.40	0.573
127 .53	1.571	16.20	3.392	225.44	0.463
156 .96	1.728	19.93	4.174	277.35	0.414
196 .20	1.849	24.92	5.219	346.79	0.354
215 .82	1.865	27.41	5.741	381.44	0.325

Table 3: Results of constant speed test at 2000rpm (Tenera Oil palm biodiesel, B_2,100)

Load $(T_1-T_2)g$(N)	Fuel Consumption (kg/h)	Torque (T1-T2)r (N-m)	Brake Power (kW)	Brake m.eff.pr. (kN/m2)	Brake sp.F.c. (kg/kW-h)
78.48	1.271	9.97	2.088	138.74	0.609
117.72	1.484	14.95	3.131	208.05	0.474
142.25	1.661	18.07	3.785	251.47	0.439
176.58	1.696	22.43	4.698	312.14	0.361
196.20	1.836	24.92	5.219	346.79	0.352
215.82	1.855	27.41	5.741	381.44	0.323

Table 4: Results of constant speed test at 2000rpm (Dura biodiesel blend,B,10)

Load $(T_1-T_2)g$(N)	Fuel Consumption (kg/h)	Torque $(T_1-T_2)r$ (N-m)	Brake Power (kW)	Brake m.eff.pr. (kN/m^2)	Brake sp.F.c. (kg/kW-h)
98.10	1.117	12.46	2.610	173.40	0.428
107.91	1.183	13.70	2.869	190.65	0.412
137.34	1.381	17.44	3.653	242.70	0.378
166.77	1.535	21.18	4.436	294.75	0.346
196.20	1.610	24.92	5.219	346.79	0.308
206.01	1.993	26.16	5.479	364.05	0.364

Table 5: Results of constant speed test at 2000rpm (Tenera biodiesel blend, $B_2$10)

Load $(T_1-T_2)g$(N)	Fuel Consumption (kg/h)	Torque $(T_1-T_2)r$ (N-m)	Brake Power (kW)	Brake m.eff.pr. (kN/m^2)	Brake sp.F.c. (kg/kW-h)
78.48	1.049	9.97	2.088	138.74	0.502
98.10	1.175	12.46	2.610	173.40	0.450
117.72	1.263	14.95	3.131	208.05	0.403
137.34	1.335	17.44	3.653	242.70	0.365
176.58	1.550	22.43	4.698	312.14	0.330
206.01	1.562	26.16	5.479	364.05	0.285

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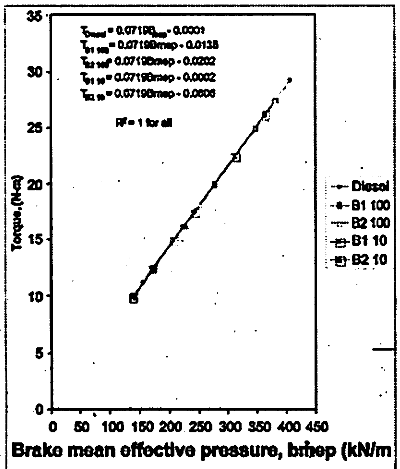

Figure 5.25: Comparison of Torque performance at 2000rpm

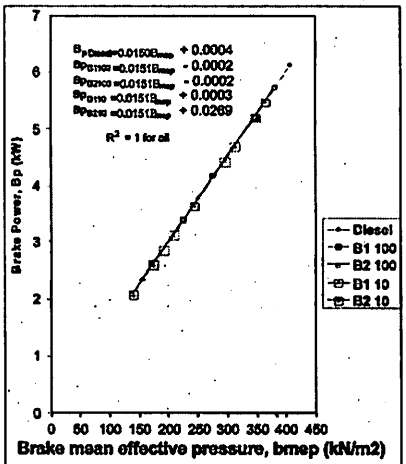

Figure 5.28: Comparison of Brake Power performance at 2000rpm

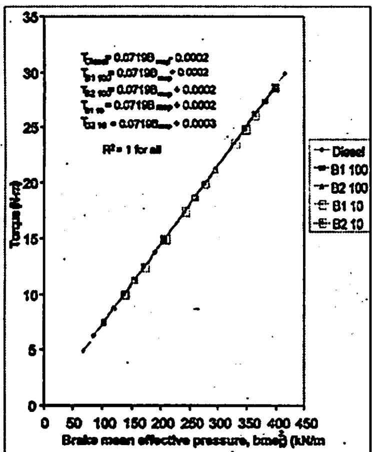

Figure 5.26: Comparison of Torque performance at 1500rpm

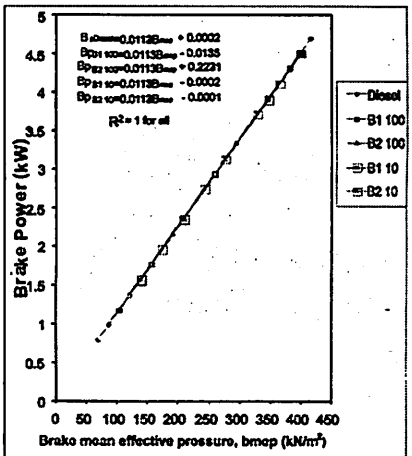

Figure 5.29: Comparison of Brake Power at 1500rpm

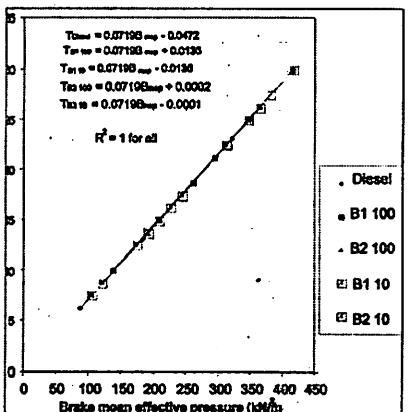

Figure 5.27: Comparison of Torque performance at 1100rpm

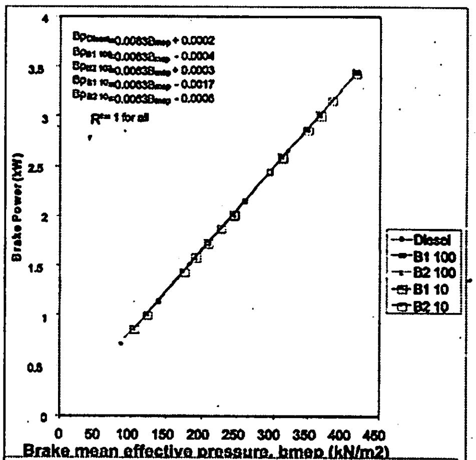

Figure 6: Comparison of Power performance at 1100rpm