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Technical Analysis of Jatropha and Palm Kernel Biodiesel as the Sole Fuel Source for Powering Diesel Engines

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ABSTRACT

This paper presents the technical assessment of Jatropha and palm kernel biodiesels as substitutes for fossil diesel in diesel engines. The pure biodiesels of Jatropha and palm kernel and varied blends of the biodiesels and fossil diesel in different proportions by volume were run on a single cylinder two stroke diesel engine test rig located at the Thermodynamics laboratory of the Mechanical Engineering laboratory, KNUST. Performance indicators measured include brake power, brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and brake mean effective pressure. Results for fossil diesel were used as baseline values for comparative analysis. Results showed that the average BTE values for Jatropha B100 and palm kernel B100 were respectively, 26.1% and 28.38%, and were found to be 24.75% and 30.60% higher than the BTE value for fossil diesel, respectively, indicating that a diesel engine that runs on the B100s will give relatively higher overall thermal efficiencies. However, the most significant conclusion from the study is that blends of 20% by volume of biodiesel and lower values can be used in diesel engines with no, or minor modifications in the engine settings.

Keywords: *brake power, jatropha oil biodiesel, palm kernel oil biodiesel, brake thermal efficiency, cold start, diesel engine.*

NOMENCLATURE

BMEP	Break mean effective pressure, kPa
B.P	Break power, kW
B.S.F.C	Break specific fuel consumption, kg/h
BTE	Break thermal efficiency, %
B5	Blend of 5% biodiesel and 95% fossil diesel by volume, %vol.
B10	Blend of 10% biodiesel and 90% fossil diesel by volume, %vol.
B20	Blend of 20% biodiesel and 80% fossil diesel by volume, %vol.
B50	Blend of 50% biodiesel and 50% fossil diesel by volume, %vol.
B100	100% biodiesel, %vol.
JB	Jatropha biodiesel
PKB	Palm Kernel biodiesel

$C.V_f$	Higher calorific value, kJ/kg
D	Cylinder bore, m
F	Fuel volume flow rate, cm^3/s
ρ_f	Fuel density, kg/m^3
L	Piston stroke, m
$\dot{m}_f$	Fuel mass flow rate, kg/h
n_R	number of crank revolutions
N	Engine rotational speed, rpm
R_T,	Torque arm, m
$\bar{S}_p$	Mean piston speed, m/s
T	Torque, N.m
V_d	Swept volume, m^3
W	Load, Newtons

1. INTRODUCTION

For the past three decades, there had been increased interest in using biodiesels instead of fossil diesel in CI engines. There is a significant amount of research being conducted to lower the cost of producing biodiesel as well as to increase its performance in CI engines. However, research is not conclusive on the exact characterisitics of biodiesels operated on diesels engines. Biodiesels are known to have higher viscosity and specific gravity than fossil diesel, which affects fuel consumption, injection timing, and spray pattern. Since the cetane number for biodiesels is higher as compared with fossil diesel (No. 2 fuel oil), a shorter ignition delay will results, which will require an advance combustion timing. Canakci and Van Gerpen [1] showed that B100 (100% biodiesel) had a higher brake specific fuel consumption (BSFC) when compared to fossil diesel. This reflects its lower heating value (about 12% lower than diesel).

According to Utlu and Kocak [2] the respective average decrease of torque and power values of 'waste frying oil methyl ester' (WFOME) was 4.3% and 4.5% due to higher viscosity and density and lower heating value (8.8%). Hansen et al. [3] observed that the brake torque loss was 9.1% for B100 biodiesel relative to D2 diesel at 1900 rpm as the results of variation in heating value (13.3%), density and viscosity. And Murillo et al. [4] found that the loss of power was 7.14% for biodiesel compared to diesel on a 3-cylinder, naturally aspirated (NA), submarine diesel engine at full load, but the loss of heating value of biodiesel was about 13.5% compared to diesel. It was reported that there was no significant difference in engine power between pure biodiesel and diesel [5, 6, 7, 8, 9 and 10]. For instance, Lin *et al.* [5] found that the maximum and minimum differences in engine power and torque at full load between PD (petroleum diesel) and 8 kinds of VOME (vegetable oil methyl ester) fuels were only 1.49% and −0.64%, 1.39% and − 1.25%, respectively, due to higher viscosity, higher BSFC (brake specific fuel consumption), higher oxygen content and higher combustion rate of biodiesel. Qi et al. [7] reported this trend, the explanation is that engine delivers fuel on volumetric basis and biodiesel density is higher than that of diesel, which supplies more biodiesel to compensate the lower heating value.

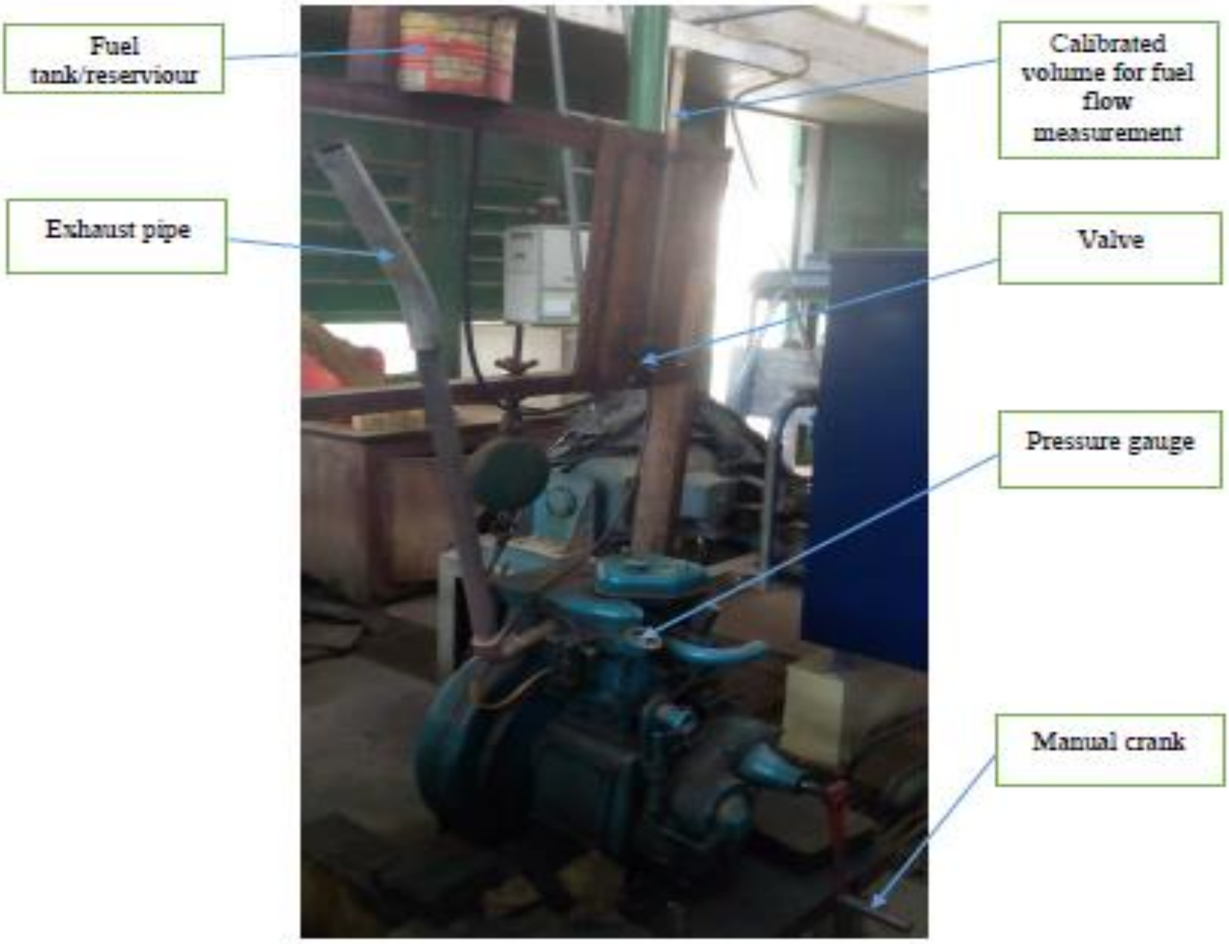

Figure 1: Coventry victor co. engine loading mechanism.

The main goal of this study is to investigate the possibility of using jatropha and palm kernel biodiesels as replacement for fossil based diesel in the diesel/compression ignition engine. The study presented is entirely technical and makes use of fundamental engine performance indicators.

2. DESCRIPTON OF SET UP

Figures 1 shows a pictorial view of the Coventry Victor company limited engine used for the tests with sufficient manual instrumentation. The Victor engine is a two stroke single-cylinder direct injection compression ignition engine with a bore of 89 mm, a stroke of 137 mm, and a displacement of 0.852 litres. The engine is governed to operate at 2500 rpm maximum, with a fine speed adjustment of ±30.

The L70V model Victor company limited experimental engine is of the vertical cylinder arrangement and employs air cooling. Although the nature of the engine does not permit indicated power and air inflow measurement it is chosen because of its simplicity, ruggedness, lower fuel consumption and its ability to eliminate mixture variation.

3. INSTRUMENTATION

The internal combustion engine test rig was reasonably instrumented for the various measurements (see figure 2).The following parameters were measured during the test: torque arm (metres), variable load (in pounds), rotational speed (revolutions per minute), volume of fuel consumed (in cubic centimetres), and time (in seconds). The test engine has the friction brake type of dynamometer (see figure 1) integrated with the engine crankshaft for loading the engine. A drum with a rectangular groove is cast into the protruding part of the engine crankshaft and provided with a rope, hanger and gauge for measuring the load imposed on the engine (see figure 2). A conical depression is fabricated into the middle end part of the drum for attaching a tachometer (tachometer accuracy: ± 0.05%) to enable engine speed measurement. The arrangement for fuel flow rate measurement is shown in figure 2. It consists of a fuel reservoir, transparent liquid hose, and a calibrated transparent tube (with accuracy ± 0.5%). The opening of the valve allows direct flow of fuel from the calibrated tube to the engine. The engine depends on a manual crank for starting.

4. DESCRIPTION OF TEST

The performance tests were performed with Jatropha and palm kernel biodiesels, fossil diesel, and various blends of the biodiesels and fossil diesel at different loads. The lubrication oil level was first checked for adequacy and effectiveness. The blended fuel samples were prepared by the use of a measuring cylinder and a stirrer. For each fuel sample, the time within which 40 cubic centimeters of fuel was consumed and the rotational speed of the engine were measured with a stop watch and a tachometer, respectively. The experiment was first run at no load conditions. Standard weights were then added in increments of 5 pounds and the test was performed for 5 incremental values whilst measuring volumetric fuel consumption and engine rotational speed. Available air vents in the windows were adjusted to ensure sufficient air supply to the apparatus since the engine is air- cooled.

Table 1: Victor coventry diesel engine parameters.

Engine Model:	L70V	**High Idling**	2500+/-30
Engine Type:	2-stroke, Vertical Cylinder, Air-Cooled Diesel	**Injection Timing**	No load: 2 CAD before TDC to 4 CAD after TDC Full load: 6 to 15 CAD before TDC
No. of Cylinders	1	**Cooling System**	Cooled by air
C Compression ratio	1 16	**I Injection pressure**	540 bar
Injection type	Direct injection	**Number of nozzles**	1 Unit Injector
Nozzle hole diameter	0.15 mm	**Combustion System**	Direct Injection

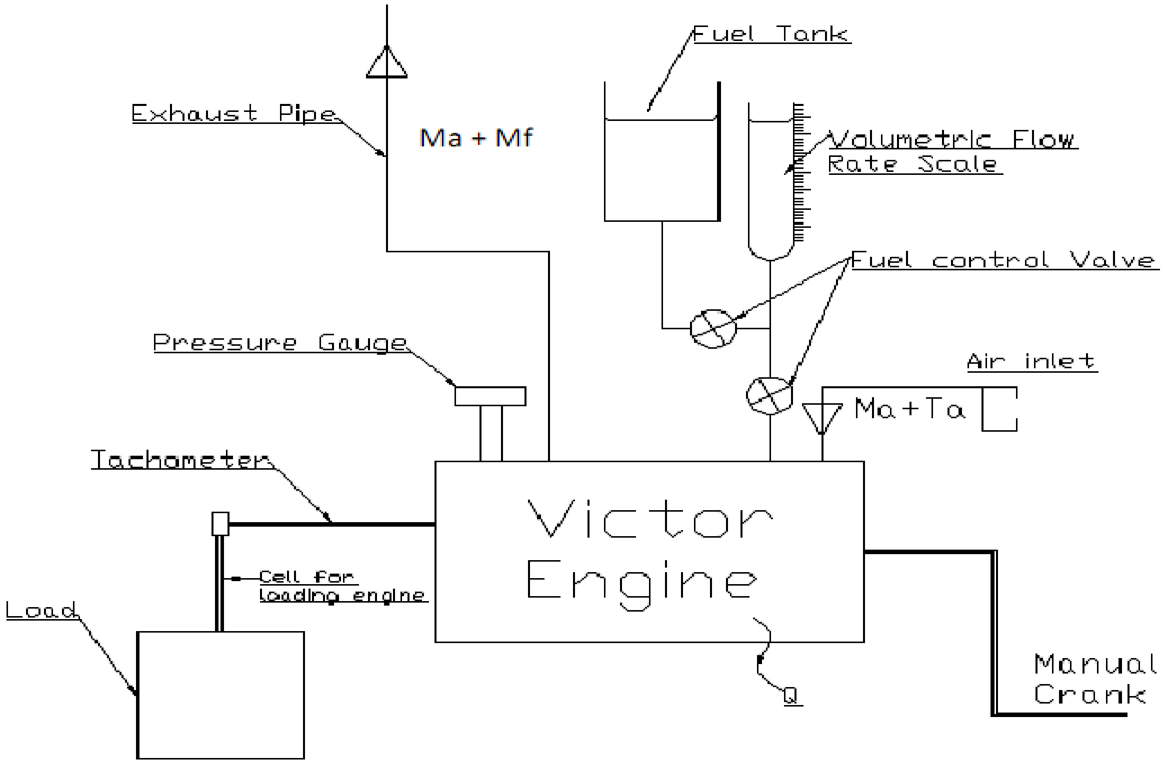

Figure 2. Schematic drawing of experimental set up with instrumentation.

5. RESULTS AND ANALYSIS

Table 2: Results for 100% fossil diesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1442	40	271	0.442	0.00	-	0.00	0.00	0.00
2	22.3	1439	40	244	0.491	0.50	0.974	8.13	24.67	3.35
3	44.5	1430	40	268	0.447	1.00	0.447	17.71	49.23	6.68
4	66.8	1423	40	220	0.545	1.49	0.365	21.72	73.90	10.02
5	89.0	1413	40	200	0.599	1.98	0.303	26.12	98.46	13.35
6	111.0	1297	40	164	0.731	2.26	0.323	24.52	122.80	16.65
Average values					0.54±0.11	1.21±0.87	0.482±0.28	16.37	61.51	8.34

Table 3: Results for Jatropha B100.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1449	40	336	0.378	0.00	-	0.00	0.00	0.00
2	22.3	1433	40	312	0.407	0.50	0.810	11.30	24.67	3.35
3	44.5	1416	40	264	0.480	0.99	0.485	18.85	49.23	6.68
4	66.8	1405	40	256	0.496	1.47	0.336	27.23	73.90	10.02
5	89.0	1403	40	240	0.529	1.96	0.269	33.96	98.46	13.35
6	111.0	1390	40	224	0.566	2.42	0.234	39.17	122.80	16.65
Average values					0.48±0.07	1.22±0.91	0.43±0.23	21.75	61.51	8.34

Table 4: Results for PALM KERNEL B100.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kWh)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1432	40	344	0.363	0.00	-	0.00	0.00	0.00
2	22.3	1429	40	312	0.401	0.50	0.800	12.24	24.67	3.35
3	44.5	1417	40	280	0.446	0.99	0.451	21.73	49.23	6.68
4	66.8	1404	40	244	0.512	1.47	0.348	28.16	73.90	10.02
5	89.0	1390	40	232	0.539	1.94	0.277	35.32	98.46	13.35
6	111.0	1390	40	232	0.539	2.42	0.222	44.06	122.80	16.65
Average values					0.47±0.07	1.22±0.90	0.42±0.23	23.59	61.51	8.34

Table 5: Results for ablend of (50%) fossil fuel and (50%) Jatropha biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP / (kPa)	T/ (N.m)
1	0.0	1411	40	344	0.359	0.00	-	0.00	0.00	0.00
2	22.3	1332	40	296	0.417	0.47	0.893	9.51	24.67	3.35
3	44.5	1368	40	272	0.453	0.96	0.474	17.91	49.23	6.68
4	66.8	1361	40	248	0.497	1.43	0.348	24.39	73.90	10.02
5	89.0	1336	40	232	0.532	1.87	0.285	29.83	98.46	13.35
6	111.0	1387	40	208	0.593	2.42	0.245	34.63	122.80	16.65
Average values					0.48±0.08	1.19±0.90	0.45±0.26	19.38	61.51	8.34

Table 6: Results for a blend of (50%) fossil fuel and (50%) palm kernel biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1419	40	380	0.322	0.0	-	0.00	0.00	0.00
2	22.3	1421	40	296	0.414	0.50	0.831	10.54	24.67	3.35
3	44.5	1411	40	256	0.478	0.99	0.485	18.07	49.23	6.68
4	66.8	1411	40	248	0.494	1.48	0.333	26.27	73.90	10.02
5	89.0	1400	40	224	0.546	1.96	0.279	31.37	98.46	13.35
6	111.0	1387	40	216	0.567	2.42	0.234	37.38	122.80	16.65
Average values					0.47±0.09	1.23±0.91	0.43±0.24	20.61	61.51	8.34

Table 7: Results for a blend of (50%) jatropha biodiesel and (50%) palm kernel biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1441	40	328	0.384	0	-	0.00	0.00	0.00
2	22.3	1429	40	312	0.404	0.50	0.831	11.73	24.67	3.35
3	44.5	1420	40	288	0.437	0.99	0.485	21.48	49.23	6.68
4	66.8	1413	40	264	0.477	1.48	0.333	29.41	73.90	10.02
5	89.0	1407	40	240	0.525	1.97	0.279	35.47	98.46	13.35
6	111.0	1396	40	232	0.543	2.43	0.234	42.43	122.80	16.65
Average values					0.46±0.06	1.23±0.91	0.432±0.24	23.42	61.51	8.34

Table 8: Results for B5-Jatropha biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1449	40	304	0.395	0.00	-	0	0.00	0.00
2	22.3	1432	40	256	0.469	0.50	0.938	8.50	24.67	3.35
3	44.5	1432	40	240	0.501	0.99	0.504	15.81	49.23	6.68
4	66.8	1411	40	224	0.536	1.48	0.362	22.04	73.90	10.02
5	89.0	1409	40	192	0.626	1.97	0.318	25.06	98.46	13.35
6	111.0	1404	40	184	0.653	2.43	0.268	29.72	122.80	16.65
Average values					0.53±0.097	1.23±0.91	0.48±0.27	16.86	61.51	8.34

Table 9: Results for B10-Jatropha biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1442	40	312	0.386	0.00	-	0.00	0.00	0.00
2	22.3	1432	40	288	0.418	0.50	0.834	9.62	24.67	3.35
3	44.5	1419	40	272	0.443	0.99	0.447	17.97	49.23	6.68
4	66.8	1408	40	232	0.519	1.48	0.352	22.83	73.90	10.02
5	89.0	1404	40	224	0.538	1.97	0.274	29.29	98.46	13.35
6	111.0	1393	40	200	0.603	2.43	0.248	32.36	122.80	16.65
Average values					0.48±0.08	1.23±0.91	0.43±0.24	18.68	61.51	8.34

Table 10: B20-Jatropha biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1445	40	320	0.379	0.00	-	0.00	0.00	0.00
2	22.3	1424	40	304	0.399	0.50	0.799	10.18	24.67	3.35
3	44.5	1402	40	272	0.446	0.98	0.455	17.90	49.23	6.68
4	66.8	1396	40	248	0.489	1.47	0.334	24.39	73.90	10.02
5	89.0	1365	40	232	0.523	1.91	0.274	29.73	98.46	13.35
6	111.0	1351	40	216	0.561	2.36	0.238	34.17	122.80	16.65
Average values					0.47±0.07	1.20±0.88	0.42±0.23	19.40	61.51	8.34

Table 11: Results for B5-Palm kernel biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(KW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1423	40	880	0.136	0.00	-	0.00	0.00	0.00
2	22.3	1417	40	464	0.259	0.50	0.521	16.16	24.67	3.35
3	44.5	1381	40	336	0.357	0.97	0.370	22.75	49.23	6.68
4	66.8	1377	40	240	0.500	1.45	0.346	24.32	73.90	10.02
5	89.0	1353	40	224	0.536	1.89	0.283	29.72	98.46	13.35
6	111.0	1350	40	208	0.577	2.35	0.245	34.34	122.80	16.65
Average values					0.39±0.17	1.19±0.88	0.35±0.11	21.22	61.51	8.34

Table 12: Results for B10-Palm kernel biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(KW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1416	40	424	0.284	0.00	-	0.00	0.00	0.00
2	22.3	1404	40	296	0.407	0.49	0.827	9.77	24.67	3.35
3	44.5	1399	40	272	0.442	0.98	0.452	17.85	49.23	6.68
4	66.8	1395	40	240	0.501	1.46	0.343	23.58	73.90	10.02
5	89.0	1390	40	228	0.528	1.94	0.272	29.73	98.46	13.35
6	111.0	1388	40	212	0.568	2.24	0.235	34.43	122.80	16.65
Average values					0.45±0.10	1.19±0.86	0.43±0.24	19.23	61.51	8.34

Table 13: Results for B20-palm kernel biodiesel.

Test no.	Measured parameters				Calculated parameters					
	W/(N)	N/(rpm)	V/(cc)	t/(s)	$\dot{m}_f$ /(kg/h)	B.P /(kW)	B.S.F.C/ (kg/kW)	BTE /(%)	BMEP/ (kPa)	T/ (N.m)
1	0.0	1419	40	288	0.420	0.00	-	0.00	0.00	0.00
2	22.3	1409	40	248	0.487	0.50	0.987	8.34	24.67	3.35
3	44.5	1399	40	240	0.504	0.98	0.513	15.99	49.23	6.68
4	66.8	1389	40	224	0.540	1.46	0.370	22.25	73.90	10.02
5	89.0	1372	40	196	0.617	1.92	0.321	25.62	98.46	13.35
6	111.0	1356	40	188	0.643	2.36	0.272	30.29	122.80	16.65
Average values					0.53±0.08	1.20±0.88	0.49±0.29	17.08	61.51	8.34

Fuel mass rate of flow $(\dot{m}_f,\ )$

Tables 2 to 13 show measured and calculated results for the varied fuel samples and blends tested. The fuel mass rate of flow is given as

$$\dot{m}_f = 3.6\left(\frac{F.\,cm^3/s}{10^3}\right)\rho_f \,\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1),$$

where F represents the volume rate of flow in cubic centimeters per second and ρ_f is the density of fuel in kilogramme per cubic meter. Using the density values shown in table 14 for fossil diesel, Jatropha biodiesel and Palm Kernel biodiesel, the fuel rate of flow was determined for all fuel samples (see column 6 of tables 2 to 13). The thermo-physical properties shown in table 13 were measured at the Chemistry laboratory of the College of Science, KNUST.

The fuel mass flow rate ($\dot{m}_f$) to some extent shows the fuel consumption of an engine. However, it cannot be used independently to explain the fuel consumption/fuel economy of an engine until it is related to the brake power developed. Pure fossil diesel recorded the highest mass flow rate values ranging between 0.442 and 0.731 kg/h followed by Jatropha B5 with values ranging between 0.395 and 0.653 kg/h (see column 6 of tables 2 to 13). The lowest fuel mass flow rate range of values of between 0.2838 and 0.5676 kg/h was recorded for palm kernel B10. It can be observed that the average fuel flow rate values for the pure biodiesels of Jatropha (0.48±0.07 kg/h) and palm kernel (0.47±0.07 kg/h) and the fuel blends were relatively lower than the average fuel flow rate value for fossil diesel (0.54±0.11 kg/h). For the fuel blends of jatropha biodiesel and petroleum based diesel, it can be seen that the average fuel mass flow rate decreases from B5 (with average value of 0.53±0.097 kg/h) through to B10 ($\dot{m}_f$ = 0.48±0.08 kg/h) to B20 (m_f = 0.47±0.07 kg/h) and experiences a sudden rise in value at B50 (0.48±0.08 kg/h). However, the average fuel mass flow rate for the blends of palm kernel biodiesel and petroleum based diesel increases from B5 (with an average value of 0.39±0.17 kg/h) through B10 (with average value of 0.45±0.10 kg/h) to B20 (with value 0.53±0.08 kg/h) then experiences a sudden decrease in value at B50 (with average value of 0.47±0.09 kg/h).Jatropha and palm kernel diesel have higher viscosity than fossil diesel (see table 14), thus, viscosity is reduced by blending. However, it can, generally be observed that for both Jatropha biodiesel and palm kernel biodiesel, the mass rate of flow improved as the percentage by volume of the biodiesel component of the fuel blends increase. This could be attributed to the improved flow characteristics and well as good engine lubricity associated with biodiesels.

Table 14: Thermo-physical properties of the pure fuel samples.

Fuel Property	**Fuel Samples**			
	Unit	Fossil diesel	Jatropha biodiesel	Palm Kernel biodiesel
Viscosity	Cst	3.15 (40 °C)	3.576 (50 °C)	5.3 (40 °C)
Density	g/ cm^3	0.832 (40 °C)	0.8809 (15 °C)	0.868 (25 °C)
Flash point	°C	70	174	191
Gross calorific value	kJ/kg	45,457	39,340	36,764
Cetane number	-	51.5	58.4	61.5
Acid value	mg KOH/g	0.06	0.38	0.24
Total glycerol	%	-	0.17	0.08
Free glycerol	%	-	0.01	0.001

Bake Power (B.P., kW)

The brake power (b.p) of an engine is the useful power at the crankshaft of the engine. Brake Power is given by

$$\text{Brake Power, b.p} = \frac{2\pi W R_T N}{60\times10^3},\ \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where W is the load in Newtons, R_T = torque arm in meters, and N, the rotational speed in revolutions per minute. The magnitude of brake power developed at any instant in response to the combustion mixture strength (FA_{act}/FA_{stoic}), indicates to some extent the efficacy of the engine to convert heat energy released during combustion, to work, the difference being the friction power. The power output of biodiesel depends on its uniformity, quality, and load conditions under which the fuel is burnt. Jatropha B5, Jatropha B10, and the blend 50%Jatropha biodiesel/50%palm kernel biodiesel recorded the maximum brake power range of values of between 0 and 2.43 kW. The minimum brake power value of the range was recorded at zero load whereas the maximum value occurred at a maximum load of 25 lb (i.e. 111 N) for all three fuel samples. The trend of results shows that for any fuel sample, the brake power developed generally increases as the load imposed on the engine increases. The lowest range of brake power values (i.e. 0 to 2.26 kW) was recorded for fossil diesel. It can also be seen that the brake power values obtained for the pure biodiesels and the varied blends of biodiesels were much higher than the corresponding values for fossil diesel (see column 7 of tables 2 to 13). This could be attributed to the high density atomization that characterizes biodiesel flow in injection systems. Jatropha B100, Palm kernel B100 and palm kernel B10 exhibited the same working brake power range of 0 to 2.42 kW. Similarly, the working break power range of values for Jatropha B10 and palm kernel B10 were also very close with ranges of 0 – 2.43 kW and 0 – 2.42 kW (see column 7 of tables 9.0 and 12.0). Jatropha B20 and Palm kernel B20 also recorded the same break power range of values of 0 to 2.36 kW (see column 7 of tables 10.0 and 13.0). The results show that the brake power range of values for blends of the same volumetric proportion of both Jatropha and palm kernel biodiesel (B50, B10 and B20), with the exception of B5, were approximately the same. The relative difference between the maximum brake power values for palm kernel B5 and Jatropha B5 was 3.29% whereas the relative difference between the maximum brake power values for Jatropha B10 and palm kernel B10 was 0.41% with Jatropha biodiesel consistently giving a comparatively higher maximum brake power value. This could be attributed to the relatively higher gross calorific value of Jatropha biodiesel (39,340 kJ/kg) compared with palm kernel biodiesel (36,764 kJ/kg).

Brake Specific fuel consumption (B.S.F.C)

The brake specific fuel consumption is defined as the fuel flow rate per unit power output. It is a measure of the efficiency of the engine in using the fuel supplied to produce work, and is a criterion of economical power production. The brake specific fuel consumption is given as.

$$\mathrm{Bsfc}=\frac{\dot{m}_f}{P_b} \qquad (3)$$

where $\dot{m}_f$ is the mass flow rate of the fuel and P_b is the brake power. It is desirable to obtain a lower value of *b.s.f.c,* hence, a lower b.s.f.c value indicates better fuel economy. Palm kernel B5 recorded the lowest range of brake specific fuel consumption values of 254 to 521 g/kWh followed by jatropha B20 with a range of 238 to 799 g/kWh, and palm kernel B100% with a range of brake specific fuel consumption values of between 222 and 800 g/kWh (see figure 4).The highest brake specific fuel consumption range of values was recorded for palm kernel B20 with values ranging between 272 and 987 g/kWh with an average value of 445g/kWh. However, fossil diesel recorded the highest average specific fuel consumption value of 482±0.28 g/kWh (with a values ranging between 323 and 974 g/kWh). The average brake specific fuel consumption values of jatropha B100 (430±0.23 g/kWh) and palm kernel B100 (420±0.23 g/kWh) are 12.91% and 14.78% better than fossil diesel, respectively, in terms of fuel economy. Also, the ***b.s.f.c***. values for jatropha B10 and palm kernel B10 are respectively 20.58% and 38.03% better than fossil diesel at full load. This fundamentally suggest that the pure biodiesels of Jatropha and palm kernel and the varied fuel blends tested have better fuel economy than fossil diesel. The average brake specific fuel consumption of Jatropha B5 is higher than the average value for palm kernel B5 by 35.41% whereas the average brake specific fuel consumption value for Jatropha B10 is 1.26% higher than that for palm kernel B10. The only difference occurred at B20 where the fuel economy of Jatropha (420±0.23 g/kWh) recorded an average value 17% better than palm kernel (490±0.20 g/kWh). Therefore, it can be seen that the fuel economy of palm kernel biodiesel is slightly better than that of Jatropha biodiesel except at B20 although Jatropha biodiesel gives a relatively higher brake power value (see figure 4). Also, the blend of 50% Jatropha biodiesel and 50% palm kernel biodiesel by volume recorded an average fuel economy (i.e. 412±0.24 g/kWh) 16.99% better than fossil diesel (482±0.28 g/kWh). Furthermore, Jatropha B20 and palm kernel B20 recorded fuel economy 35.22% and 8.32% better than fossil diesel, respectively. The relative better fuel economy of biodiesels over fossil diesel can be attributed to the comparatively lower calorific value and rich oxygen content of biodiesels. These results compare fairly well with the findings of ***Sharma et. al*** [11]. Figure 4 shows that the b.s.f.c increases with increasing torque, reaches a maximum value between 3.35 and 6.68 N.m and decreases as the torque reaches a maximum value for all fuel samples. The initial torque value of zero was not used in plotting figure 4 since BSCF is indeterminate at zero torque.

Brake Thermal efficiency (%)

Brake thermal efficiency (BTE) of a fuel is partly based on fuel characteristics such as viscosity, specific density, and flash point and partly on the calorific value of the fuel. Break thermal efficiency is given as

$$\mathrm{B.T.E}=\frac{\mathrm{b.p}\left(\mathrm{kW}\right)}{\dot{m}_f\left(\mathrm{kg}/\mathrm{s}\right)\times \mathrm{C.V}_f\left(\frac{\mathrm{kJ}}{\mathrm{kg}}\right)} \qquad (4)$$

where b.p is brake power, $\dot{m}_f$ is fuel mass rate of flow, and $C.V_f$ is the gross calorific value of fuel. The gross calorific values used for calculating the BTE values for the fuel blends were calculated based on the gravimetric ratios of the constituents of the blends since density is a physical property. The calorific value of jatropha B100 (see table 14) is 13.46% less than the calorific value of diesel whereas the calorific value of palm kernel B100 is 19.12% less than that of diesel. A fuel sample with lower calorific value must burn more fuel in order to release a unit quantity of energy. The lowest average brake thermal efficiency was recorded for Jatropha B5 (with a value of 16.86%) followed by palm kernel B20 (with an average value of 17.08%) and Jatropha B10 (with an average value of 18.68%). The brake thermal efficiency performance of Jatropha B20 (19.40%), Jatropha B50 (19.38%) and palm kernel B10 (19.23%) are slightly higher than that of fossil diesel (16.37%) with relative difference values of 18.51%, 18.14% and 17.47%, respectively. The average BTE values for Jatropha B100 (21.75%) and palm kernel B100 (23.59%) were respectively, 32.86% and 44.11% higher than the BTE value for fossil diesel, indicating that a diesel engine that runs on the B100s will give relatively higher overall thermal efficiencies. This will result in higher brake mean effective pressure, a smaller displacement volume and a corresponding reduction in engine size (see equation 5).

$$P_m = \frac{P_b\, n_R}{V_d N\, n} \qquad (5)$$

For Jatropha biodiesel and its blends, it can be observed that the average BTE value generally decreases as the percentage by volume of jatropha biodiesel decreases in the fuel blend with jatropha B100 having the highest average BTE value of 21.75% and jatropha B5 having the lowest average BTE value of 16.86%. However, the average BTE value for Jatropha B20 (19.40%) is 0.10% higher than the average BTE value for Jatropha B50 (19.38%). Considering the closeness of the two values, it can be said that the average BTE values for Jatropha B50 and Jatropha B20 are approximately the same.

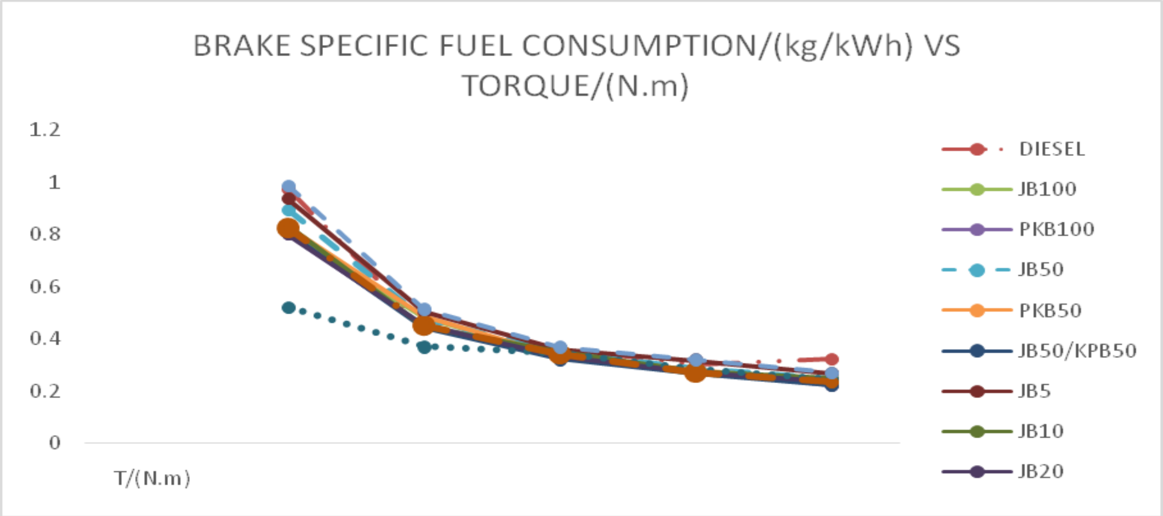

Figure 3: Graph of brake specific fuel consumption versus torque for all test samples.

On the other hand, the average fuel conversion efficiency (FCE) values for palm kernel biodiesel and its blends were comparatively higher than the corresponding values for Jatropha biodiesel and its blends. Palm kernel B100 recorded the highest average fuel conversion efficiency (BTE) value of 23.59 %, 1.44 times higher than the BTE value for diesel and 1.08 times higher than the average BTE value for Jatropha B100. The average BTE value for palm kernel decreases from B100 to B20 (18.51%), then increases from B20 to B5 (21.22%). Notwithstanding the relatively lower calorific values and comparatively viscous nature of the biodiesels of jatropha and palm kernel and the respective fuel blends relative to diesel, the thermal conversion efficiencies of the pure biodiesels and varied fuel blends were higher than that of fossil diesel. This can be attributed to the reported [12] better lubricity, improved cetane rating, and the inherent tendency of biodiesels to undergo more complete combustion than fossil diesels due to their high oxygen content, partially compensating for the high energy density. These findings are in close conformity with the results of [13] and [11]. Figure 4 shows that the B.T.E generally increases with increasing torque for all fuel samples**.** The superior fuel conversion efficiency that the biodiesels and their blends have over fossil diesel can easily be seen from figure 5. The initial torque value of zero was not taken into consideration in plotting figure 5 since BTE is indeterminate at zero torque.

Brake Mean Effective pressure (B.M.E.P)

The brake mean effective pressure is the average pressure the engine can exert on the piston through one complete operating cycle. It is the average pressure of the gas inside the engine cylinder based on net power. The B.M.E.P can be calculated as

$$\mathrm{B.M.E.P} = \frac{2\pi T n_R}{V_d \times 10^3} \qquad (6)$$

where the torque reaction (T) is equal to the product of the effective lever arm length (l_b) and the net force on the lever arm, F.

$T = W \times R_T$, n_R is the number of crank revolutions per cycle

($n_R = 1$ in this case), and V_d is the swept volume given by

$$V_d = \frac{\pi D^2}{4} \times L = \frac{\pi \times 0.089^2}{4} \times 0.137 = 8.52 \times 10^{-4}\ \mathrm{m}^3.$$

The measured torque arm, $R_T = 0.15\ m$. Results show that the B.M.E.P values were comparable for all fuel samples used including the pure biodiesels of Jatropha and palm kernel, fossil diesel, and the fuel blends used with the B.M.E.P ranging from 0 to 122.80 kPa and an average value of 61.51 kPa. This could be attributed to the fact that the test engine was subjected to the same standard weights for the same engine displacement for all fuel samples tested.

Mean Piston Speed ($\bar{S}_p$)

Mean piston speed: Measures comparative success in handling loads due to inertia of the parts and/or engine friction. Mean piston speed is given by

$$\bar{S}_p = 2LN \qquad (7),$$

where *N* is the rotational speed of the crankshaft in *rev/s* and L is the stroke of the cylinder. The average mean piston speed values for all fuel samples tested were within the range of 6.24 to 6.50 m/s with Jatropha B50 recording the lowest mean piston speed value of 6.24 m/s. Jatropha B5 recorded the highest average 'mean piston speed' value of 6.50 followed by Jatropha B100, Jatropha B10, and a blend of 50%Jatropha biodiesel/50% palm kernel diesel, all recording a value of 6.47 m/s. The results show that the 'mean piston speed' values recorded for Jatropha B100 and the Jatropha, fossil diesel blends (range: 6.24 for B50 to 6.50 m/s for B5) were relatively higher than the corresponding values for palm kernel biodiesel (range: 6.32 for B5 to 6.44 m/s for B100). The 'mean piston speed' for Jatropha B100 and palm kernel B100 were respectively, 0.62% and 0.16% higher than the mean piston speed for fossil diesel (value 6.43 m/s). These results compare fairly well with literature (Heywood, 1988) considering that the test rig is a single cylinder engine.

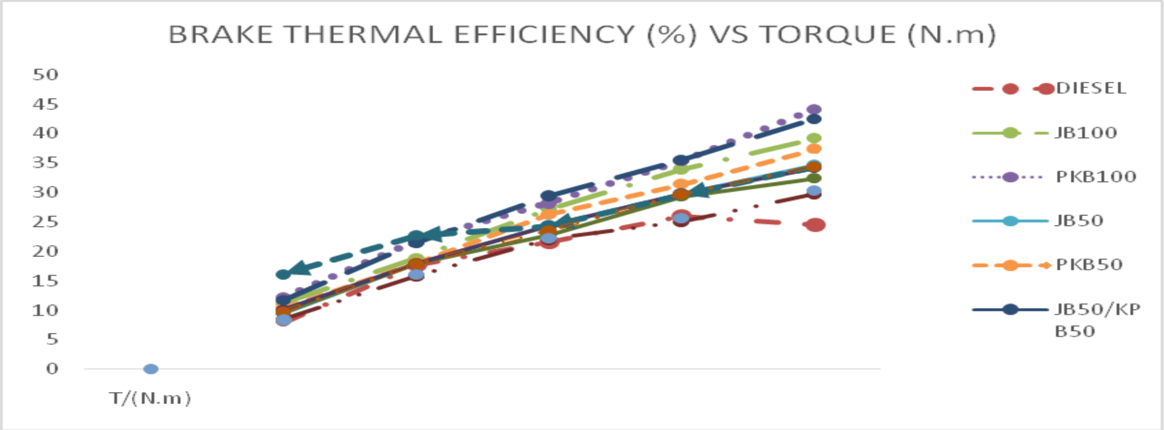

Figure 4: Brake thermal efficiency versus torque for all test sample.

6. CONCLUSIONS

The technical analysis of Jatropha and palm kernel biodiesels as alternative fuel sources to fossil diesel has shown that:

1. For both Jatropha biodiesel and palm kernel biodiesel, the mass rate of flow improved as the percentage by volume of the biodiesel component of the fuel blends increased as a result of the improved flow characteristics and well as good engine lubricity associated with biodiesels. The average fuel mass flow rate values for the pure biodiesels of Jatropha (0.48±0.07 kg/h) and palm kernel (0.47±0.07 kg/h) and the fuel blends were relatively lower than the average fuel mass flow rate value for fossil diesel (0.54±0.11 kg/h).
2. The brake power values obtained for the pure biodiesels and the varied blends of biodiesels were much higher than the corresponding values for fossil diesel. The brake power range of values for blends of the same volumetric proportion of both Jatropha and palm kernel biodiesel (B50, B10 and B20), with the exception of B5, were approximately the same. The relative difference between the maximum brake power values for palm kernel B5 and jatropha B5 was 3.29% whereas the relative difference for maximum brake power values for jatropha B10 and palm kernel B10 was 0.41% with jatropha biodiesel consistently giving a comparatively higher maximum brake power value as a result of the relatively higher calorific value of jatropha biodiesel (39,340 kJ/kg) compared with palm kernel biodiesel (36,764 kJ/kg).
3. The average brake specific fuel consumption values of jatropha B100 (430±0.23 g/kWh) and palm kernel B100 (420±0.23 g/kWh) are 12.91% and 14.78% better than fossil diesel, respectively, in terms of fuel economy. The fuel economy of palm kernel biodiesel is slightly better than that of Jatropha biodiesel except at B20 although jatropha biodiesel gives a relatively higher brake power value. The pure biodiesels of Jatropha and palm kernel and the varied blends recorded comparatively higher fuel B.S.F.C values than fossil diesel due to the lower calorific value and rich oxygen content of biodiesels.
4. The average B.T.E values for Jatropha B100 (26.10%) and palm kernel B100 (28.30%) were respectively, 24.75% and 30.60% higher than the BTE value for fossil diesel, indicating that a diesel engine that runs on the B100s will give relatively higher overall thermal efficiencies.
5. The B.M.E.P was comparable for all fuel samples used including the pure biodiesels of Jatropha and palm kernel, fossil diesel, and the fuel blends used

with the B.M.E.P ranging from 0 to 245.61 kPa and average value of 123.02 kPa

6. Blends of 20% biodiesel by volume and lower values can be used in diesel engines with no, or minor modifications. The B100 of Jatropha and palm kernel exhibit good thermal performance but cannot be used directly in diesel engines due to the relatively high density and viscosity which has the potential to affect cold start performance and may also lead to clogging in fuel lines and filters

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