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ORIGINAL RESEARCH ARTICLE

EFFECTS OF OPERATIONAL CONDITIONS ON EXERGY BEHAVIOUR OF BIOMASS DENSIFICATION SYSTEM AND DURABILITY OF THE DENSIFIED BIOMASS

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ABSTRACT

Energy resources such as electricity and fuel are used to power biomass densification system for production of solid biofuel, however, energy consumption of the densification equipment has led to high cost of production of the solid biofuel. Meanwhile, energy stored in fuel or the electricity is being used to budget for the work or power requirements during densification of biomaterials which are mostly considered as energy consumption. The energy consumption does not give appropriate recognition to the exact or useful energy from the energy source that is energy output of the system. This study to investigates the effects of operational conditions of a biomass densification system on the exergy behaviour of a biomass densification system. The exergy parameters such as exergy input and exergy output were considered to determine the behaviour of biomass densification system. The conditioned biomass materials at 6%, 10% and 14% moisture contents (MC) were densified at selected applied pressures of 186.56, 211.38, 236.25, 261.17, 286.07 and 310.85 MPa, while each selected pressure was applied at different speeds of 10, 20, 30, 40, 50 mm/min. The exergy parameters obtained were subjected to statistical analysis using IBM SPSS 20.0 to determine the effects of the operational conditions on the exergy behaviour of biomass densification system. The highest mean values of exergy output of 0.3562 J and 0.4033 J were observed at 10 mm/min when pressure of 310.85 MPa was applied using sawdust and huskdust both at 6% MC, respectively to produce one-unit average weight of 12g of biofuel. The least mean values of exergy output of 0.1001 J and 0.1738 J were observed at 50 mm/min when pressure of 186.56 MPa was applied using sawdust and huskdust both at 14% MC respectively. Additionally, densified biomass of high durability was obtained when both sawdust and huskdust were densified at 10% Mc wet basis while the less durable densified biomass was obtained at 6% MC for sawdust and huskdust. Therefore, the operational conditions of biomass densification system such as applied pressure, speed of pressing piston and MC of biomass materials had effects on the exergy input and exergy output as well as the durability of the densified biomass.
It was then concluded from this study that the operational conditions of biomass densification system can affect the exergy behavior of the system and the quality of densified biomass.

1.0 Introduction

The bulkiness of loosed biomass materials like plant stalk, straw, chaff, sawdust, rice husk, etc. are reduced by the densification process to a dense form as solid biofuel or densified biomass known as pellets or briquettes for easy handling, transportation and storage and also helps to solve the problem of residual disposal.

The different types of densification equipment as reported by Grover and Mishra (1996) such as reciprocating press type, screw extruder press and hydraulic piston press have been developed, evaluated and the densified biomass materials have also been evaluated to ascertain their durability.

The energy resources such as electricity and fuel are used to power the biomass densification system for production of solid biofuel, however, energy consumption of these densification equipment have been intensively discussed and high energy consumption as observed by Wu et al. (2014) and Stelte et al. (2012). This has caused increased production cost of the solid biofuele.

Mostly, consideration is usually given to analysis of energy stored in fuel or the energy draw from electricity while budgeting for the work or power requirements during densification of agricultural and biomaterials without given appropriate recognition to exergy analysis of the system. Exergy analysis gives useful information on both the quantity and quality aspects of the energy utilization because it measures the exact energy used by the system. This implies that energy analysis of a system is not enough to analyse the energy of the system because it focuses on the quantity of energy resources only (Dincer, 2000; Dincer and Cenger, 2001).

In this regard, an exergy analysis can be a useful tool for providing information on the impact of energy resources used by the system. It can also assess the technical performance of biomass densification devices in terms of energy usage by the system.

The aim of this study is to investigate the effects of operational conditions of a biomass densification system on the exergy behaviour of the system. The exergy behaviour of the biomass densification system has to do with energy that is made available and drawn from the power source during densification operation known as exergy input; the exact or actual energy being used to densify the biomass materials is referred to as exergy output; exergy loss is a form energy is being lost which could be as a result of frictional forces between the wall of the pressing channel, piston head and biomaterials. This study gave consideration to the exergy input and exergy output of the system as well as on the durability of densified biomass.

2. Materials and methods

2.1 Experimental Material

The selected biomass materials were Rice husk and Sawdust. The rice husk was sourced from rice processing centre along Idofian Road, Jimba, in Ifelodun LGA, Kwara State while sawdust was obtained from wood industry at Offa Garage, Ilorin, Kwara State. Rice husk was reduced in size using burr mill to aid densification process.

The laboratory rig developed by Kudabo, (2017) was incorporated into the Universal Testing Machine (UTM) of 300 KN capacity (S300CT, Testometric Company Ltd, United Kingdom) used in controlling and monitoring the operational conditions of the densification system. Figures 1 and 2 show schematic diagram of the densification rig and its laboratory set up with the UTM.

The measuring equipment used were electronic weighing scale of model number cL. 201 made by OHAUS in China for measuring the quantity of biomass material to be densified for each of the experiment, electronic moisture analyser of model number LSC – 50 made by OHAUS company, China to determine the MC of the sample before densification and multimeter of model number 179TRUERMS made by FLUKE Company, USA to read the current and voltage flow into the UTM.

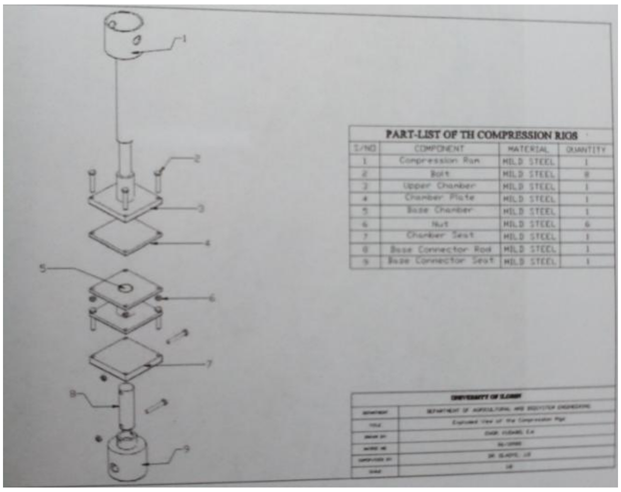

Figure 1: Section View of Densification Rig

Figure 2: Laboratory Set Up for Biomass Densification System

2.2 Experimental Procedure

The exergy behavior of laboratory biomass densification system was analysed using laboratory experimental biomass densification system.

The sawdust and rice husk were mixed in ratio 2:1 (Huskdust) as first biomass material and whole sawdust as the second biomass material were used to carry out the experiment. The bio-materials were conditioned to the moisture contents of approximately 6, 10, 14% and were verified using electronic moisture analyser before densification operation. Then, 14g of conditioned sawdust at 6%,14.5g at 10% and 15g at 14% moisture contents, respectively, which filled the pressing chamber of the densification rig were densified using applied pressures of 186.56, 211.38, 236.25, 261.17, 286.07, 310.85 MPa, to produce a unit of solid biofuel (a briquette). Each selected pressure was applied at different speeds of 10, 20, 30, 40, 50 mm/min. The procedure was repeated for 12g of conditioned huskdust at 6%, 12.5g at 10% and 13g at 14% moisture contents. The exergy parameters of the biomass densification system such as exergy input and exergy output were determined using Equations 1, 2 and 3.

i. Electrical energy used to power the biomass densification system which is the exergy input into UTM was determined by reading the current and voltage flow into UTM using the multimeter placed in their positions, the time taken to densify the biomass materials from the UTM and then the exergy input was estimated using Equation (1) as given by Olotu (2019).

$$Ex_{in(Elect)} = En_{in(Elect)} = IVt \quad (1)$$

where:

$Ex_{in(Elect)}$ = Exergy input in Joule
$En_{in(Elect)}$ = electrical energy in kWh
I = current in amperes
V = voltage in volts
t = was the time it took the densification system to produce a unit of densified biomass.

ii. The actual (exact) energy used to densify biomass materials which is exergy output was determined using equation (2) as given by Olotu (2019).

$$W_S = \frac{P_A \pi R_A^2 d \exp\left(\frac{4\mu\lambda Y_n}{d} - 1\right) \exp - \left(\frac{4\mu\lambda M}{d}\right)}{4m\mu\lambda} \quad (2)$$

where,

$$Y_n = M - \frac{aMm_a}{AM \log_e\left(\frac{P_A + C}{C}\right) + am_a} \tag{3}$$

W_s = exergy output in Joule
Y_n = distance moved by the piston to densify biomass materials in m
P_A = applied pressure of the press in MPa
A= cross sectional area of the pressing channel in m^2
M= initial height of the biomaterial inside the pressing channel before compaction in mm
m_a = mass of the biomass material in kg
d= diameter of the pressing chamber in mm
μ= friction coefficient
λ= compaction ratio of radial and axial pressures
C and a are biomass materials constants

iii. Durability Index

The densified biomass materials from sawdust and huskdust were subjected to tumbling test to determine their durability. The expressions used are stated in Equations 4 and 5.

Tumbling test was used for testing the durability of briquetted fuel. The cuboid formed by angle iron frame having dimensions of 30 × 30 × 45 cm and fixed over hollow shaft diagonally was used to conduct the tumbling test. The sample of briquettes was put inside the cuboid and rotated for15 minutes, thereafter the briquette was taken out, weighed and percent loss was calculated by using formula given by Senga et al. (2012).

$$P_{LD} = \frac{W_{D1} - W_{D2}}{W_{D1}} \times 100 \tag{4}$$

$$\text{Durability Index} = 100 - P_{LD} \tag{5}$$

where:

P_{LD} = Percent weight loss due to tumbling (%)
W_{D1} = Weight of briquette before tumbling (g)
W_{D2} = Weight of briquette after tumbling (g)

The experimental design for this experiment was 2 X 3 X 5 X 6 factorial design in a Complete Randomized Block, this was used to analyse the effects of processing conditions on exergy parameters of densification system. The factors in the factorial design are at 6 levels of applied pressure and 5 levels of speed of operation as the machine parameters and 3 levels of moisture content of the biomass materials using 2 different types of biomass materials. Each treatment combination was performed in three (3) replicates, making a total of 540 values.

The results of both exergy parameters such as exergy input and exergy output were subjected to statistical analysis to determine the effect of operational conditions of the biomass densification system on the selected exergy parameters.

The data obtained were analyzed statistically using IBM SPSS version 20.0. The NDMRT was carried out on the outcome and graphical interpretations were presented.

3. Results and Discussion

The investigation on the effects of operational conditions of biomass densification system on exergy behaviour of the system were carried out statistically using SPSS to analyse the data obtained during the laboratory investigation. The results of the analysis and the interpretation of the results with respect to applied pressure, operating speed and moisture content of the two (2) different biomass materials were discussed.

3.1 Exergy Input into Biomass Densification System from the Power Source

The values of the exergy input calculated during the experiment were subjected to statistical analysis. The results show that moisture content of biomass materials (sawdust and huskdust), the pressure exerted during densification and the operating speeds of the system were significant $p \leq 0.05$. This showed that the densification operational conditions had effect on the exergy input from the power source.

3.1.1 Effects of Applied Pressure on the Exergy Input from Power Source

It was observed from Table 1 that the applied pressure on the piston inside densification chamber for compaction of sawdust and huskdust had significant effect on the exergy input $p \leq 0.05$. The levels of the applied pressure that led to the significant difference in the exergy input as determined by NDMRT as shown in Table 1 revealed that all the levels of applied pressure were significantly different $P \leq 0.05$.

Table 1 depicted that the applied pressure level of 186.56 MPa had the least value of the exergy input and it increases as the level of the applied pressure increases, that is, the highest value of the exergy input was obtained at applied pressure level of 310.85 MPa. Figures 2 and 3 further showed the variation of exergy input as pressure exerted on piston during compaction of sawdust and huskdust increase. This might be that as the pressure applied on the piston inside densification chamber increased, more energy was demanded causing excess energy being drawn from the power source to carry out the operation leading to increase in exergy input. This is mostly referred to as energy consumption and the pressure which the biomaterials were exposed to in this research work was as a result of increase in the force applied during the process.

Table 1: Effect of Applied Pressure on Exergy Input from the Power Source

S/N	Applied Pressure (MPa)	Mean Exergy Input (Joule)	
		B1	B2
1	186.56	516.90^{a}	534.56^{a}
2	211.38	542.83^{b}	551.80^{b}
3	236.25	564.97^{c}	567.71^{c}
4	261.17	584.85^{d}	581.02^{d}
5	286.25	607.08^{e}	594.19^{e}
6	310.85	632.81^{f}	607.09^{f}

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

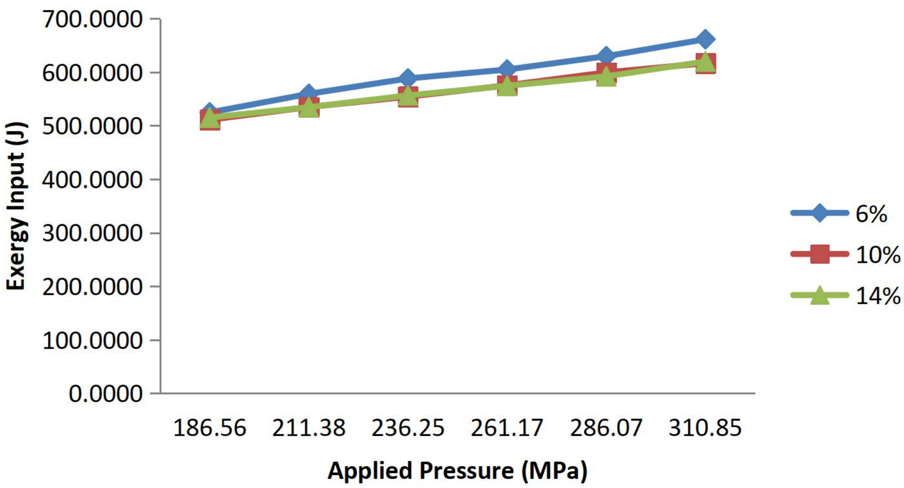

Figure 2: Effect of Applied Pressure on the Exergy Input using Sawdust at Different Moisture Contents

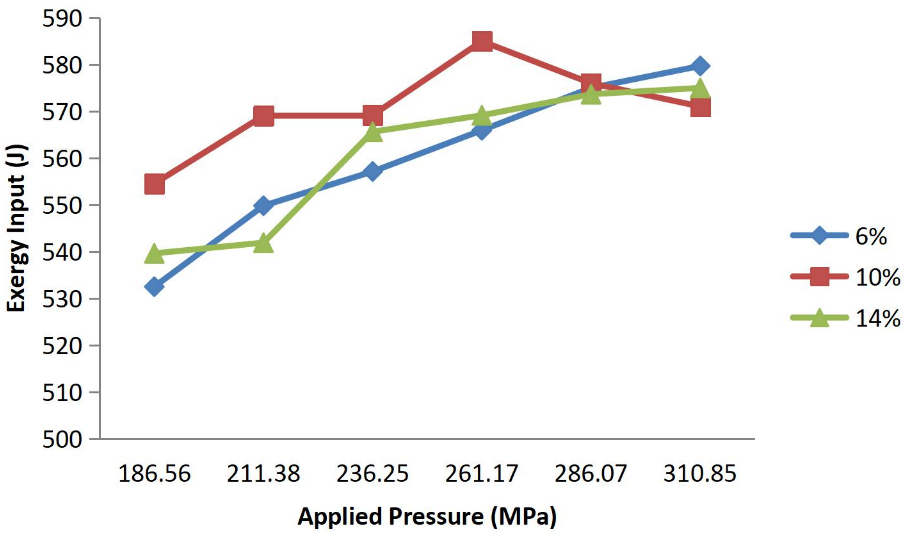

Figure 3: Effect of Applied Pressure on the Exergy Input using Huskdust at Different Moisture Content

3.1.2 *Effects of Operating Speed on the Exergy Input during Densification Operation*

The results of the effects of the operating speed of the densification system as in Table 2 showed that the operating speed had significant effect on the exergy input from the power source $p \le 0.05$. NDMRT was employed to determine the level of the operating speed that contributed to this significant difference as shown in Table 2 which indicated that all the levels of operating speed were significantly different $p \le 0.05$.

From Table 2, the operating speed level 10mm/min had the highest value of the exergy input and exergy input decreases as the level of the operating speed increases, that is the least of the value of exergy input was obtained at operating speed level of 50mm/min. More so, Figures 4 and 5 further showed that there were decreases in exergy input as operating speed of the densification system increases for all MC for both sawdust and huskdusk. This could be that as the operating speed of the densification system increases, less time was being spent to attain the applied force set for the densification process thus, leading to low exergy input from the power source to the densification system.

Table 2: Effect of Operating Speed on Exergy Input of the Densification System

S/N	Operating speed (mm/min)	Mean Exergy Input (Joule)	
		B1	B2
1	10	1226.84_a	1200.4_a
2	20	660.77_b	650.07_b
3	30	429.76_c	432.47_c
4	40	318.17_d	334.89_d
5	50	239.01_e	245.76_e

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

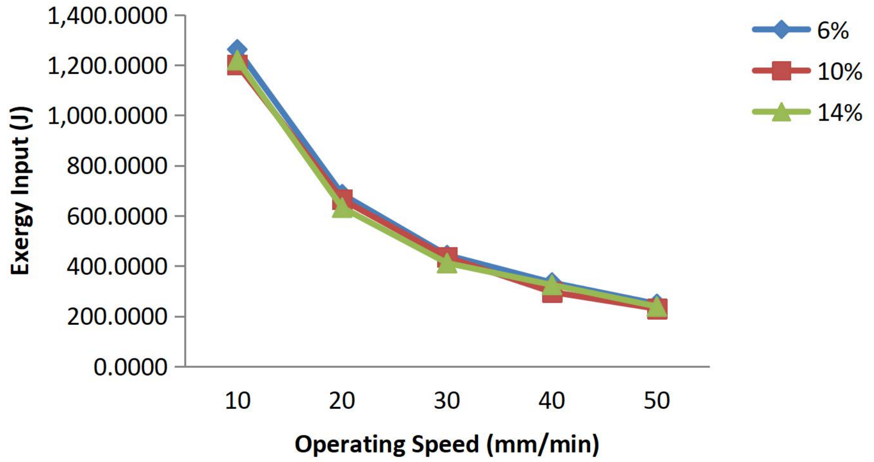

Figure 4: Effect of Operating Speed on the Exergy Input using Sawdust at Different Moisture Contents

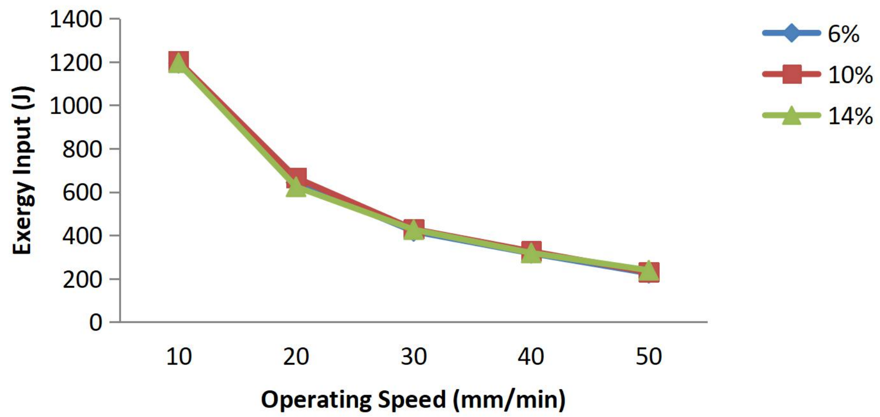

Figure 5: Effect of Operating Speed on the Exergy Input using Huskdust at Different Moisture Contents

3.1.3 Effects of Moisture Content of Saw Dust and Husk Dust on the Exergy Input Power Source

Table 3 showed that the moisture content of sawdust and huskdust has significant effect on the exergy input of densification system. This was in line with the results of the studies carried out by Andreiko and Grochowicz (2007) which observed that moisture content of biomass materials has influence on the energy consumption of the densification system.

NDMRT used to determine the level of the moisture content of sawdust and huskdust that led to this significant difference as shown in Table 3 indicated that all the levels of moisture content of huskdust were significantly different $p \leq 0.05$ while all the levels of moisture content of sawdust did not show significant difference.

Table 3 showed that sawdust at 6% moisture content had the highest value of exergy input followed by 14% moisture content while the least value of exergy input was obtained at 10% moisture content of the saw dust, though the exergy input at 10% and 14% were not significantly different from each other. Huskdust gave a result that has highest value of exergy input at 10% followed by 14% moisture content and the least value was obtained with 6%. Table 3 revealed that exergy input neither increased nor decreased as the moisture content of the huskdust increased or decreased, while when sawdust was used, the results showed an increase in exergy input as the moisture content of sawdust increased. However, there was no significant difference between exergy input of the system when sawdust at 10% and 14% moisture contents were used ($p \leq 0.05$). This shows that increase or decrease of biomass moisture content might not really affect the exergy input of the system within the studied range.

Table 3: Effects of Moisture Content of Saw Dust and Huskdust on the Exergy Input from Power Source into Densification System

S/N	Moisture content (%)	Mean Exergy Input (Joule)	
		B1	B2
1	6	594.01_a	560.35_a
2	10	565.30_b	581.62_b
3	14	565.41_b	572.20_c

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

3.2 Exergy Output by Densification Operation System

In this work, the NDMRT showed that moisture content of biomass materials; sawdust and huskdust, the applied pressure during densification and the operating speeds of the system were significant $p \leq 0.05$. This proved that the densification operational conditions had significant effect on the exergy output of the densification system.

3.2.1 Effects of Applied Pressure on the Specific Work done (Exergy Output) by Densification Operation System

Table 4 revealed that applied pressure for compaction of sawdust and huskdust had significant effect on the exergy output $p \leq 0.05$. The levels of the applied pressure that led to the significant difference in the exergy output were determined using NDMRT as shown in Table 4. It was observed that all the levels of applied pressure were significantly different $p \leq 0.05$.
The reason could be because as there was an increase in pressure exerted on the piston inside the pressing chamber, there was also a change in pressure build-up inside the chamber. This result agrees with Stelte et al. (2012) who reported that the pressure at which the biomass materials is exposed to during densification process had significant impact on the process energy used for the biomass densification.

In addition, it was observed that the applied pressure level of 186.56 MPa had the least values 0.154551 J and 0.226296 J of the exergy output for sawdust and huskdust respectively and it increases as the level of the applied pressure increases. This means that the highest mean values 0.269347 J and 0.349418 J of exergy output were obtained at applied pressure level 310 MPa for the sawdust and huskdust respectively. Figures 6 and 7 showed increases in exergy output as the pressure applied on both sawdust and huskdust increases. This might be that as applied force on the piston is increased; more work is being expended on the biomass materials due to the pressure built-up inside the pressing chamber which led to high energy used by the system. This is similar with Mani et al. (2004) study, which reported that the energy requirements of a densification process depend mainly upon the exerted pressure.

Table 4: Effect of Applied Pressure on Exergy Output of the Densification System

S/N	Applied Pressure (MPa)	Mean Exergy Out (Joule)	
		B1	B2
1	186.56	0.154551_a	0.226296_a
2	211.38	0.175944_b	0.245581_b
3	236.25	0.198196_c	0.265887_c
4	261.17	0.222198_d	0.289267_d
5	286.07	0.245198_e	0.318235_e
6	310.85	0.269347_f	0.349418_f

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

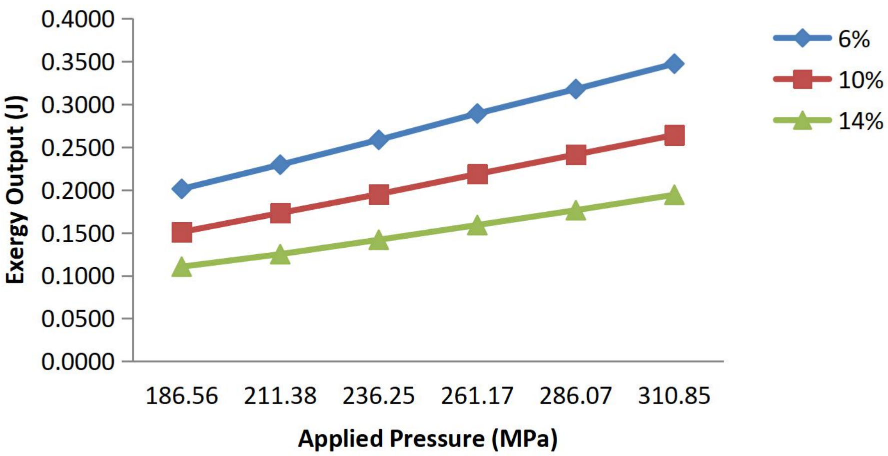

Figure 6: Effect of Applied Pressure on the Exergy Output of the Densification System using Sawdust at Different Moisture Contents

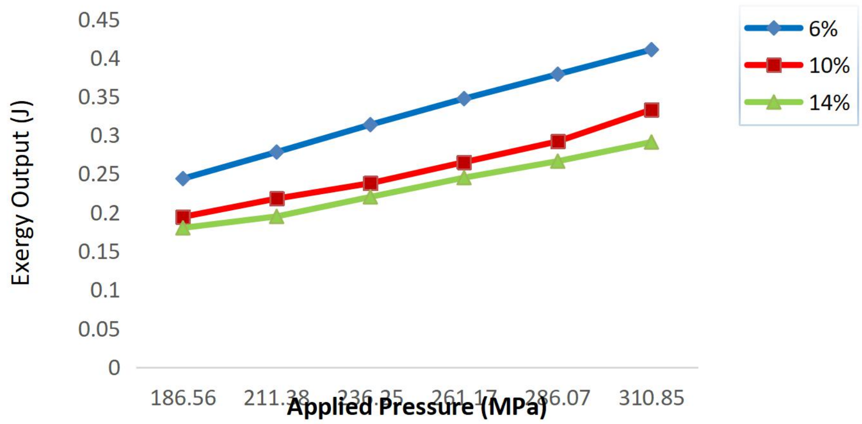

Figure 7: Effect of Applied Pressure on the Exergy Output of the Densification System using Huskdust at Different Moisture Contents

3.2.2 Effects of Operating Speed on the Exergy Output during Densification Operation

The result of the effects of operating speed of the system on the exergy output is given in Table 5 which showed that the operating speed had significant effect on the exergy output of densification system $p \leq 0.05$. This results showed that densification piston speed has slight influence on the pressure build up inside the pressing channel which depends on time taken for densification piston to travel through pressing chamber for compaction of biomass material into solid biofuel which then produce the compression work performed by the system known to be the specific work done or exergy output.

NDMRT employed to determine the level of the operating speed that contributed to this significant difference as shown in Table 5 indicated that all the levels of operating speed were significantly different $p \leq 0.05$.

The operating speed level of 10mm/min had the highest value of the exergy output and it decreases as the level of the operating speed increases as the least value of exergy output obtained at operating speed level of 50mm/min. Figures 8 and 9 showed that there was gradual decrease in exergy output as operating speed of the densification system increases at moisture contents of 6%, 10% and 14% for both sawdust and huskdust. This might be as a result of increase or decrease in the operating speed of the densification system resulted in the less or more time spent respectively to build up pressure inside the pressing channel as it attained the set up force for the system to carry out densification work on the biomass materials. Hence, this led to low or high value of exergy output of the system.

Table 5: Effect of Operating Speed on Exergy Output of the Densification System

S/N	Operating speed(mm/min)	Mean Exergy Out (Joule)	
		B1	B2
1	10	0.216541$_a$	0.305613$_a$
2	20	0.215220$_b$	0.289639$_b$
3	30	0.211852$_c$	0.282758$_c$
4	40	0.209141$_d$	0.270050$_d$
5	50	0.201774$_e$	0.264222$_e$

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

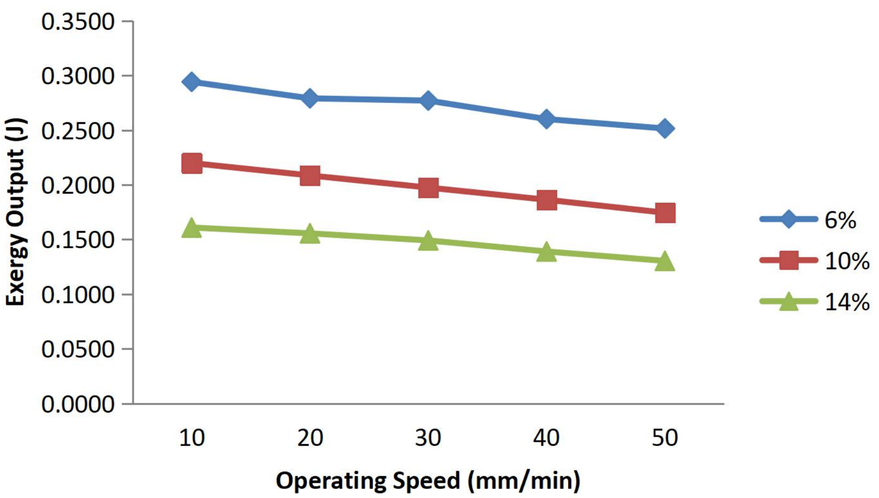

Figure 8: Effect of Operating Speeds on the Exergy Output of the Densification System using Sawdust at Different Moisture Contents

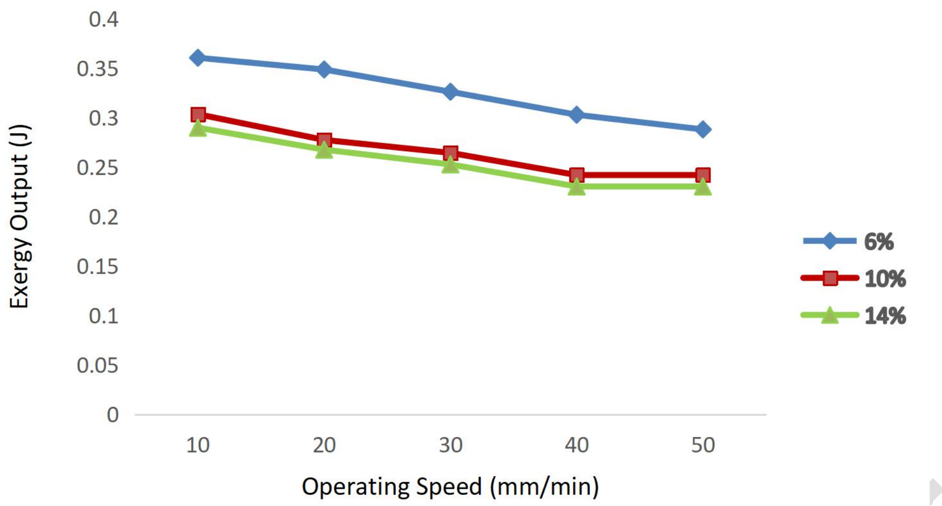

Figure 9: Effect of Operating Speeds on the Exergy Output of the Densification System using Huskdust at Different Moisture Contents

3.2.3 Effects of Moisture Content of Saw Dust on the Exergy Output of Densification Operation System

Table 6 showed that the moisture content of sawdust and huskdust had significant effect on the exergy output of densification system, this was confirmed by the studies carried out by Andreiko and Grochowicz (2007) and Mani et al (2004) that observed that moisture content of biomass materials have influence on the energy used by the densification system.

NDMRT was used to determine the level of moisture content of sawdust and huskdust that led to this significant different as showed in Table 6. The results indicated that all the levels of moisture content of sawdust were significantly different $p \leq 0.05$.

Table 6 showed that sawdust and huskdust at the moisture content of 6% had the highest value of exergy output followed by the one at 10%, while the least value of exergy output was obtained at 14% moisture content of the saw dust and huskdust. Additionally, the results revealed that all the levels of moisture content of the sawdust and huskdust were significantly different $p \leq 0.05$. This shows that as moisture content increases the exergy output of the densification system decreases which was similar to the results obtained by Nielsen et al. (2009) which stated that a decrease in the moisture content of biomass materials resulted in an increase of energy requirement of the densification system. This could be as a result of insufficient moisture between the particles of the biomass materials to aid in binding and adhesion of the biomass particles. This led to more pressure being required to bind them together and thus, leading to high demand of energy to carry out the densification process.

Table 6: Effects of Moisture Content of Saw Dust on the Exergy Out of Densification Operation System

S/N	Moisture content (%)	Mean Exergy Out (Joule)	
		B1	B2
1	6	0.274000_a	0.340411_a
2	10	0.207381_b	0.258062_b
3	14	0.151336_c	0.248869_c

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

3.3 Durability Index of the Densified Biomass

The values of the durability indices obtained during the tumbling test for each of the briquette produced were statistically analyzed. NDMRT was conducted on the durability index of densified biomass in respect to moisture content of the sawdust and huskdust, operating speed of the laboratory briquetting machine and the applied pressure as the main factors.

It was observed that moisture content of biomass material (sawdust and huskdust), the pressure applied on the densification piston and the operating speeds of the system were significant $p \leq 0.05$. This showed that the densification operational conditions had effect on the durability index of the densified biomass.

3.3.1 Effects of Applied Pressure on the Durability Index of the Densified Biomass

It was observed from NDMRT that the applied pressure on the densification piston for compacting the biomass material had significant effect on the durability index of the densified biomass $p \leq 0.05$ as shown in Table 7. It is also showed that all the levels of the applied pressure are significantly different in the durability index of the densified biomass $p \leq 0.05$.

Table 7 revealed that the applied pressure level of 186.56 MPa achieved the least value of the durability index for the briquettes produced. The durability index increases as the level of the applied pressure increases. However, the highest mean value of durability index was obtained at applied pressure level of 310.85 MPa. The mean values of the durability index at all levels of applied pressure were significantly difference from each other $p \leq 0.05$. Furthermore, Figures 10 and 11 revealed the increase in durability index of the briquettes produced as pressure applied on the densifying piston inside pressing chamber increases. This same trend was observed in the studies conducted by Krizan and Matus (2012) and Kaliyan and Morey (2009). This might be that as the force applied increased, pressure exerted on the biomass material increases making the adhesion forces between its particles to increase and hence improve the durability of the densified biomass produced.

Table 7: Effect of Applied Pressure on Durability Index of Densified Biomass from Sawdust and Huskdust using NDMRT

S/N	Applied Pressure (MPa)	Mean Durability Index	
		B1	B2
1	186.56	27.72_a	21.65_a
2	211.38	32.78_b	25.57_b
3	236.25	38.01_c	32.96_c
4	261.17	41.93_d	32.96_d
5	286.07	44.28_e	36.18_e
6	310.85	45.52_f	38.86_f

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

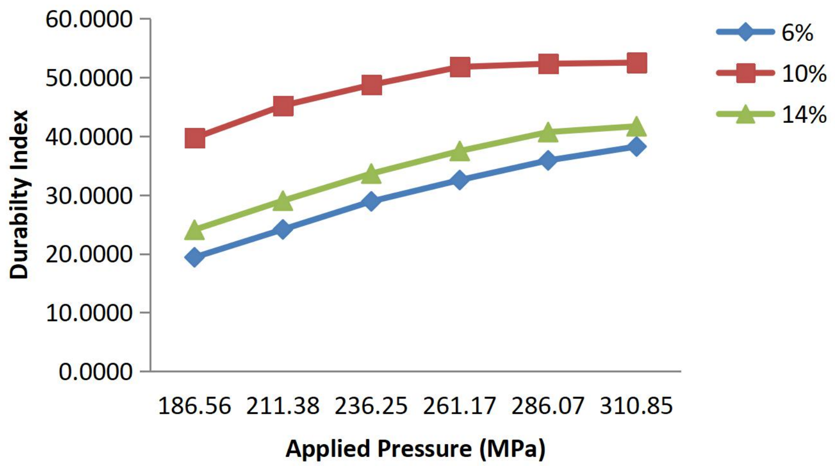

Figure 10: Effect of Applied Pressure on the Durability Index of the Densified Biomass for Sawdust at Different Moisture Contents

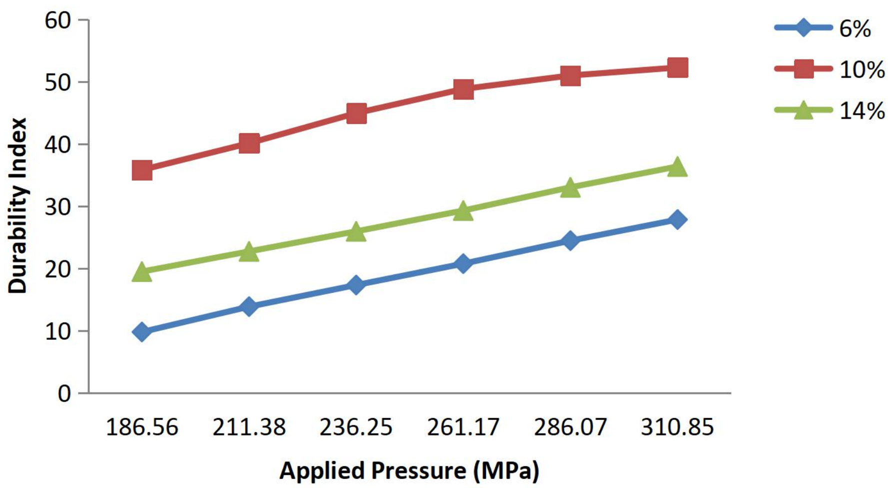

Figure 11: Effect of Applied Pressure on the Durability Index of the Densified Biomass for Huskdust at Different Moisture Contents

3.3.2 Effects of Operating Speed on the Durability Index of Densified Biomass from Sawdust and Huskdust

Table 8 showed that the operating speed of the system had significant effect on the durability index of the briquettes produced $p \leq 0.05$. NDMRT employed to determine the level of the operating speed that contributed to this significant difference showed that all levels of operating speed of the system were significantly different from each other $p \leq 0.05$ as indicated in Table 8. This confirmed a report by Obidzinski and Piekut (2015) that the operating speed of densification system has influence on the stability of the densified biomass materials. Figures 12 and 13 further revealed how there were increases in durability index as operating speed of the densification system decreases. This could be that the increase in operating speed of the system does not give room for proper arrangement of the biomass (sawdust and huskdust) particles during densification process in which the solid fuel produced easily disintegrate when subjected to tumbling test.

Table 8 also showed that the operating speed level of 10 mm/min had the highest value of the durability index and it decreases as the level of the operating speed increases, that is the least value of durability index obtained at operating speed level of 50 mm/min.

Table 8: Effect of Operating Speed on Durability Index of Densified Biomass from Sawdust and Huskdust using NDMRT

S/N	Operating speed(mm/min)	Mean Durability index	
		B1	B2
1	10	51.43_a	40.13_a
2	20	41.21_b	35.04_b
3	30	36.49_c	31.20_c
4	40	33.52_d	25.45_d
5	50	29.22_e	21.68_e

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

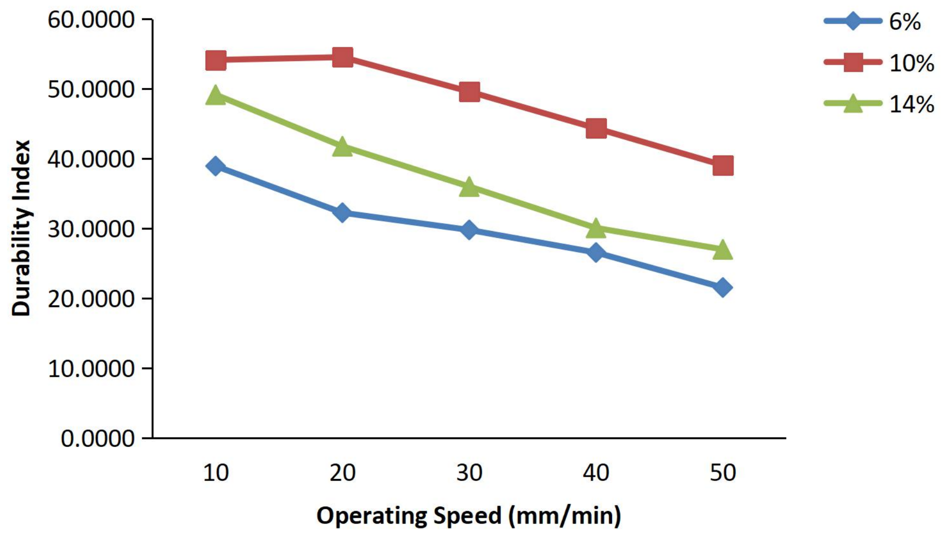

Figure 12: Effect of Operating Speed on the Durability Index of the Densified Biomass from Sawdust at Different Moisture Contents

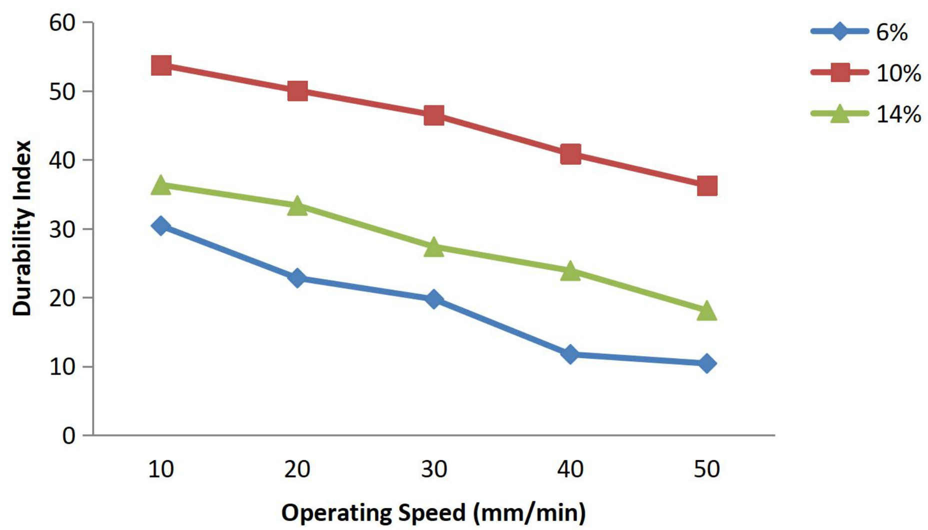

Figure 13: Effect of Operating Speed on the Durability Index of the Densified Biomass from Huskdust at Different Moisture Contents

3.3.3 Effects of Moisture Content of Sawdust and Huskdust on the Durability of Densified Biomass

Table 9 showed that the moisture content of sawdust and husk dust had significant effect on the produced briquettes p≤0.05. NDMRT used to determine the level of the moisture content of sawdust and that of the huskdust showed that there was significant difference across the two results. The levels of all the moisture content of the biomass material are significantly different from each other p≤0.05.

Similarly, it was observed that moisture content of 10% recorded the highest mean value of durability index; followed by14% t while 6% moisture content achieved the least mean value of the durability index for both sawdust and huskdust. This agrees with the studies by Keliyan and Morey (2009) that moisture content of 11% to 12% are generally used for densifying wheat- and corn-based biomass materials of high durability. Though, to obtain high durability products of a particular biomass material, the optimum densifying moisture content of biomass materials must be known because their optimum densifying moisture content differ from each other. More so, moisture content of any biomass material above or below the optimum has been shown to have a negative influence on the biomass solid fuel properties as reported by Stelte et al. (2012) and Keliyan and Morey (2009).

Table 9: Effects of Moisture Content of Saw Dust and Huskdust on the Durability Index of Densified Biomass using NDMRT

S/N	Moisture content (%)	Mean Durability Index	
		B1	B2
1	6	29.93_a	18.95_a
2	10	50.76_b	45.49_b
3	14	34.42_c	27.88_c

B1: Sawdust; B2: Huskdust: Mean with different letters are significantly different from each other

4. Conclusion

The high energy consumption of the biomass densification equipment has been observed and it does not give appropriate recognition to the exact or useful energy from the energy source which is exergy output of the system. The effects of operational conditions on the exergy behaviour of a biomass densification system as well as durability of the densified biomass was investigated. The exergy parameters such as exergy input and exergy output were considered to determine the exergy behaviour of the system. It is then concluded from this study that the operational conditions of biomass densification system affect the exergy behaviour of the system as well as the durability of the densified biomass produced. It is therefore, recommended that the optimum conditions for operating the biomass densification system that would give the best exergy behavior, high production rate and good quality solid fuel be investigated.

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