Journal of King Saud University – Engineering Sciences 32 (2020) 555–560

Contents lists available at ScienceDirect

Journal of King Saud University – Engineering Sciences

journal homepage: www.sciencedirect.com

Original article

# Mathematical modelling of die pressure of a screw briquetting machine

Joseph Ifeolu Orisaleye *, Sunday Joshua Ojolo, Joseph S. Ajiboye

*Department of Mechanical Engineering, University of Lagos, Akoka, Nigeria*

A R T I C L E  I N F O

*Article history:*
Received 9 April 2019
Accepted 29 September 2019
Available online 30 September 2019

*Keywords:*
Screw briquetting machine
Biomass briquette
Mathematical model
Die entry
Optimum die angle

A B S T R A C T

The screw briquetting machine has problems which have been attributed to poor design. There are limited theoretical studies targeted at solving problems of biomass briquetting machines. The briquetting die determines the final shape and quality of the biomass briquettes. The performance of the screw briquetting machine is also dependent on the design of the briquetting die. In this paper, mathematical models were developed to study the die pressure using a plug flow theory. Effects of die entry angle, die reduction ratio, length of briquetting die, biomass compact yield strength and friction on the die pressure were investigated using the models. Increasing the die entry angle, reduction ratio, compact yield strength and friction coefficient resulted in increase in the die pressure. Increase in length of briquetting die and friction coefficient also resulted in increase in the die pressure. Optimum die entry angle was dependent on the yield strength of compacted material and the friction coefficient at the interface between the die and the compacted material. This study is useful in developing improved screw briquetting machines.


## 1. Introduction

Developing renewable sources of energy is becoming increasingly necessary to cater for population who have limited access to energy. This is particularly so for the rural communities of developing countries which are basically agricultural based (Jekayinfa and Scholz, 2009). The regional and global potential of utilizing agricultural produce as biofuels for energy production is very high (Kaygusuz and Türker, 2002; Moreira, 2006; Ojolo et al., 2012a; Omer, 2005; Yokoyama et al., 2000). However, agricultural biomass has poor fuel properties which include low bulk density, low energy density, hygroscopic property, poor storageability and high moisture content (Lipinsky et al., 2002). For biomass to be utilized in other technologies such as the gasification and combustion technologies, they need to be compacted to forms with better fuel properties (Ojolo and Orisaleye, 2010; Ojolo et al., 2012b). This is done by densification of the biomass materials which require mechanical or thermomechanical means.

The screw briquetting machine is a promising technology for the conversion of biomass into briquettes in developing countries. The screw briquetting machine produces briquettes with holes at the centre which aids combustion. The briquettes also have a carbonized surface which improves water resistance of the briquettes. However, the existing presses have high power consumption and the screw is prone to rapid wear. Babu and Yuvaraj (2001) have attributed the problems to poor design. Gabriele et al. (2001) noted that extruders are adapted for new uses without preliminary design and optimization in many cases. A few studies (Matúš et al., 2011; Ojolo et al., 2015; Orisaleye et al., 2019; Orisaleye and Ojolo, 2019; Zhong, 1991) have investigated the design and performance of the screw of the briquetting machine using theoretical models.

Limited analysis has, however, been carried out for the design and optimization of the geometry of the die (Kováčová et al., 2014). The die of the briquetting machine provides a constriction which determines the pressure developed in the extruder and the throughput of the machine. Controlling the die pressure is important to achieve an optimal performance of the extruder with a maximum production rate. Kováčová et al. (2014), Orisaleye (2016) and Orisaleye and Ojolo (in press) investigated the pressure distribution along the die by using theoretical models. It is, however, important to determine the optimum die pressure which is required to push compacted biomass through the die. Selecting the optimum pressure would be key to designing efficient screw briquetting machines.

* Corresponding author.
*E-mail address:* jorisaleye@unilag.edu.ng (J.I. Orisaleye).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.jksues.2019.09.004
1018-3639/

**Nomenclature**

| | |
|---|---|
| $A_1$ | Cross sectional area of compact before passing through die entry |
| $A_2$ | Cross sectional area of compact after passing through die entry |
| $B$ | Diameter of hole in compacted material |
| $B_1$ | Diameter of hole in compacted biomass at inlet of die entry |
| $B_2$ | Diameter of hole in briquette in briquetting die |
| $D$ | Diameter of compacted material |
| $D_1$ | Inlet diameter of die entry |
| $D_2$ | Diameter of briquetting die / outlet diameter of die entry |
| $F1, F2, \cdots, F6$ | Forces acting on elemental slice |
| $L_d$ | Length of briquetting die |
| $L_t$ | Length of die entry |
| $l$ | Length of compact |
| $l_1$ | Length of compacted material before passing through die entry |
| $l_2$ | Length of compacted material after passing through die entry |
| $P$ | Pressure |
| $P_D$ | Ideal die pressure |
| $P_F$ | Frictional pressure at the die entry |
| $P_L$ | Die pressure in the in briquetting die |
| $P_{T1}$ | Total pressure at the die entry |
| $P_{T2}$ | Total die pressure |
| $V$ | Volume |
| $W$ | Work done |
| $Y$ | Yield strength of compacted biomass |
| $z$ | Coordinate along die axis |
| $\epsilon$ | Strain |
| $\zeta$ | Annular ratio of the briquetting die |
| $\zeta_O$ | Annular ratio at the inlet of die entry |
| $\theta_d$ | Taper angle at the die entry |
| $\theta_p$ | Taper angle of hole in compacted biomass at die entry |
| $\kappa$ | Stress transmission coefficient |
| $\mu_d$ | Friction coefficient at the compact-die interface |
| $\mu_s$ | Friction coefficient at the compact-screw end interface |
| $\sigma$ | Stress |
| $\phi_e$ | Effective angle of powder friction |
| $\chi$ | Correction factor |

In this study, mathematical models were developed to study the die pressure of a screw briquetting machine. The effects of geometrical, material and operational parameters on the pressure required for extrusion were studied during simulation of the developed models.

## 2. Methodology

Behravesh et al. (2010) and Zolfaghari et al. (2010) have observed a plug flow behaviour of plastic composite with high wood flour content above 60%. Zolfaghari et al. (2010) performed experiments to investigate the flow balance of an extrusion die for various wood flour/high-density polyethylene (HDPE) compositions. Wood flour content was varied from 40 to 70% by weight. It was observed that the pure HDPE melt behaves similar to a non-Newtonian fluid but an approximate plug flow was obtained when wood content was increased. Behravesh et al. (2010) attempted theoretical study with experimental verification to predict die pressure in wood-plastic composite extrusion. The theoretical study considered non-Newtonian flow and hot extrusion. It was observed that the experimental die pressures were higher than predictions from the non-Newtonian flow equation but lower than predictions from the hot extrusion scheme. By applying a correction factor to the hot extrusion scheme, Behravesh et al. (2010) found that the values predicted were close to those obtained experimentally.

The theoretical models for the die of the briquetting machine were, therefore, developed on the assumption of plug flow through the die. Other assumptions are that Coulomb frictional condition exists at the interface between compacted biomass and the die and slipping occurs at the boundary of the material and the die. Also, coefficient of friction is independent of pressure or temperature; pressures within the plug are non-isotropic; and strain-hardening effect on the biomass material is neglected. Fig. 1 shows the schematic diagram of the die geometry under consideration.

### 2.1. Extrusion pressure at the briquetting die

The briquetting die is the cylindrical part of the die shown in Fig. 1 positioned after the conical die entry. The briquetting die gives the briquette its final shape. A slice of plug flowing through the briquetting die is shown in Fig. 2a. The annular ratio is the ratio of the diameter of the central hole, $B_2$, to the diameter of the die or briquette, $D_2$, given as:

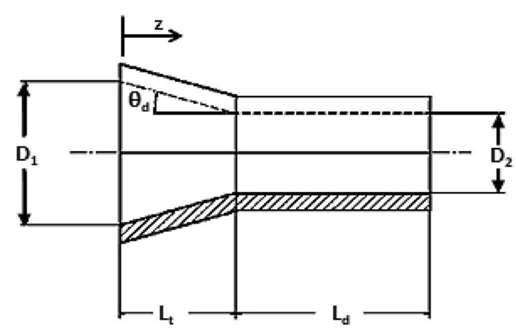


**Fig. 1.** Schematic illustration of the extrusion die geometry for the biomass briquetting machine.

$$\zeta = \frac{B_2}{D_2} \quad (1)$$

Fig. 2a shows the forces acting on the elemental slice taken from the plug flowing through the briquetting die. Using the figure, the analysis of the briquetting die pressure is developed. The forces acting on the elemental slice are (Orisaleye, 2016; Orisaleye and Ojolo, in press)

$$F1 = P\frac{\pi}{4}\left(D_2^2 - B_2^2\right) \quad (2)$$

$$F2 = (P + dP)\frac{\pi}{4}\left(D_2^2 - B_2^2\right) \quad (3)$$

$$F3 = \kappa P\pi D_2 dz \quad (4)$$

$$F4 = \mu_d F3 = \mu_d \kappa P\pi D_2 dz \quad (5)$$

The lateral stress coefficient, or stress transmission coefficient, $\kappa$, is defined in terms of the effective angle of powder friction, $\phi_e$, as (Ennis et al., 2008):

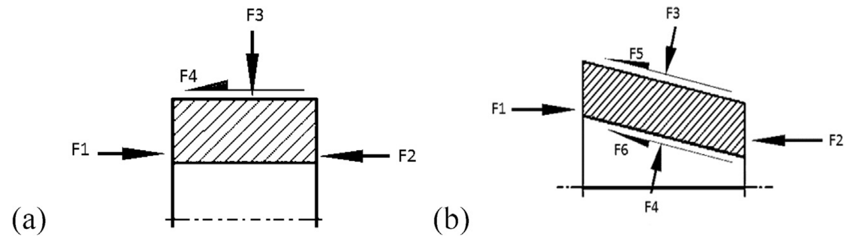


**Fig. 2.** (a) Forces acting on the plug of material flowing through the briquetting die; (b) Forces acting on the elemental slice of material flowing through the conical die entry.

$$\kappa = \frac{1 - \sin\phi_e}{1 + \sin\phi_e} \tag{6}$$

A force balance is taken over the element in the direction of the flow (the z-direction). The force balance over the element is:

$$F1 - F2 - F4 = 0 \tag{7}$$

By substituting Eqs. (2)–(6) into Eq. (7) and simplifying, the expression for the force balance is:

$$\frac{dP}{P} = -\frac{4\mu_d \kappa D_2}{D_2^2 - B_2^2} dz \tag{8}$$

During extrusion, the pressure drops to zero at the end of the die. Therefore, Eq. (8) can be integrated taking the limits from the start of the die to the end of the die as:

$$\int_0^{P_L} \frac{dP}{P} = \int_{L_d}^0 -\frac{4\mu_d \kappa D_2}{D_2^2 - B_2^2} dz \tag{9}$$

To obtain a finite solution, the reference pressure is taken as the atmospheric pressure, Eq. (9) becomes:

$$\int_{0.1}^{P_L+0.1} \frac{dP}{P} = \int_{L_d}^0 -\frac{4\mu_d \kappa D_2}{D_2^2 - B^2} dz \tag{10}$$

The die pressure, $P_L$, is therefore, expressed as:

$$P_L = 0.1 \exp\left(\frac{4\mu_d \kappa L_d}{D_2(1 - \zeta^2)}\right) - 0.1 \tag{11}$$

Mulji and Mackley (2004) proposed that experimental data can be modelled using a similar equation for the die land based on the Coulomb friction law for contact between solid bodies.

### 2.2. Extrusion pressure at the conical die entry

The study of Behravesh et al. (2010) showed that for composites with highly filled solid (wood) component, the flow behaviour is closer to the hot extrusion scheme. This requires, therefore, that the die entry pressure is modelled considering the ideal, or frictionless, die pressure and the frictional die pressure. The slice of plug flowing through the die entry is shown in Fig. 2b.

#### 2.2.1. Ideal pressure at die entry

The ideal die pressure is determined from the work done per unit volume stated as (Dieter, 1988):

$$\frac{W}{V} = \int \sigma d\epsilon \tag{12}$$

At yielding, the stress, $\sigma$, assumes the value of the yield strength, $Y$. By assuming volume of material is constant over the die entry, and taking the work done as product of pressure and volume, Eq. (12) can be written as (Orisaleye and Ojolo, in press):

$$P_D = \chi Y \ln\left\{1 + \frac{2L_t(\tan\theta_d - \zeta\tan\theta_p)}{D_2(1 - \zeta^2)} + \frac{4L_t(\tan^2\theta_d - \tan^2\theta_p)}{D_2^2(1 - \zeta^2)}\right\} \tag{13}$$

$\chi$ is the correction coefficient proposed by Behravesh et al., 2010 and it takes into consideration the strong dependence of tensile strength on temperature.

#### 2.2.2. Frictional pressure at die entry

The frictional component of the entry die pressure is analysed using the schematic diagram in Fig. 2b showing the forces acting on the elemental slice at the die entry. The forces shown in the elemental slice are expressed as (Orisaleye and Ojolo, in press):

$$F1 = P\frac{\pi}{4}\left[(D + dD)^2 - (B + dB)^2\right] \tag{14}$$

$$F2 = (P + dP)\frac{\pi}{4}\left(D^2 - B^2\right) \tag{15}$$

$$F3 = \kappa P\frac{\pi}{2}(2D + dD)dz \tag{16}$$

$$F4 = \kappa P\frac{\pi}{2}(2B + dB)dz \tag{17}$$

$$F5 = \mu_d F3 = \mu_d \kappa P\frac{\pi}{2}(2D + dD)dz \tag{18}$$

$$F6 = \mu_s F4 = \mu_s \kappa P\frac{\pi}{2}(2B + dB)dz \tag{19}$$

The force balance on the element, along the z-direction is:

$$F1 - F2 - F3\sin\theta_d + F4\sin\theta_p - F5\cos\theta_d - F6\cos\theta_p = 0 \tag{20}$$

By substituting Eqs. (14)–(19) into Eq. (20) and simplifying, the expression becomes:

$$\frac{dP}{P} = \frac{4}{D}\left\{\frac{\begin{bmatrix}(\tan\theta_d - \kappa\sin\theta_d - \mu_d\kappa\cos\theta_d) \\ -\zeta_o(\tan\theta_p - \kappa\sin\theta_p + \mu_s\kappa\cos\theta_p)\end{bmatrix}}{(1 - \zeta_o^2)}\right\}dz \tag{21}$$

The term, $\zeta_o$, is the annular ratio at the start of the die entry and is expressed as:

$$\zeta_o = \frac{B_1}{D_1} = \frac{\zeta D_2 + 2L_t\tan\theta_p}{D_2 + 2L_t\tan\theta_d} \tag{22}$$

Noting that the extrusion pressure at the briquetting die must be equal to the pressure at the end of the conical die entry, the frictional component, obtained by integrating Eq. (21), can then be stated as:

$$P_F = P_L \exp\left[\left[-\frac{4L_t}{D_2}\left\{\frac{(\tan\theta_d - \kappa\sin\theta_d - \mu_d\kappa\cos\theta_d)}{(1 - \zeta_o^2)}\right\}\right]\right] \tag{23}$$

### 2.3. Total die extrusion pressure

The total extrusion pressure at the conical die entry is the sum of Eqs. (13) and (23) given as:

$$P_{T1} = \chi Y \ln\left\{1 + \frac{2L_t \tan\theta_d}{D_2(1-\zeta^2)} + \frac{4L_t \tan^2\theta_d}{D_2^2(1-\zeta^2)}\right\} + P_L \exp\left[\left[-\frac{4L_t}{D_2}\left\{\frac{(\tan\theta_d - \kappa\sin\theta_d - \mu_d\kappa\cos\theta_d)}{(1-\zeta_o^2)}\right\}\right]\right] \quad (24)$$

The total die extrusion pressure is the sum of the total extrusion pressure at the conical die entry with the die extrusion pressure at the briquetting die. This is expressed as:

$$P_{T2} = 0.1\exp\left(\frac{4\mu_d\kappa L_d}{D_2(1-\zeta^2)}\right) + \chi Y \ln\left\{1 + \frac{2L_t \tan\theta_d}{D_2(1-\zeta^2)} + \frac{4L_t \tan^2\theta_d}{D_2^2(1-\zeta^2)}\right\} + P_L \exp\left[\left[-\frac{4L_t}{D_2}\left\{\frac{(\tan\theta_d - \kappa\sin\theta_d - \mu_d\kappa\cos\theta_d)}{(1-\zeta_o^2)}\right\}\right]\right] \quad (25)$$

## 3. Results and discussion

The effects of geometrical, operational and material parameters on the components of the die pressure are discussed in this section. The geometrical parameters investigated are the die entry angle, die reduction ratio and the length of the briquetting die. The operational parameter was the friction coefficient at the interface between the biomass material and the die. The material parameter was the yield strength of the biomass compact.

### 3.1. Effects of parameters on ideal die pressure at the die entry

The ideal pressure is required to push the compacted biomass through the reduced section of the die, assuming frictionless contact between the compacted material and the briquetting die. Fig. 3a shows the effects of the yield strength and die angle on the ideal die pressure. The ideal die pressure is seen to increase non-linearly with increase in the die angle. The ideal die pressure also depends on the yield strength of the compacted biomass material in the die entry. Fig. 3a shows that a low die pressure is developed when the yield strength of the material being processed is small. This is expected as processed material with low yield strength offers a lower resistance to the pressure applied to push it through the conical die. The yield strength is a function of temperature at the die and the degree of compaction of the biomass material. Mitchual et al. (2013) have also shown that the strength of briquettes is a function of the species of the biomass material, the particle size and the compaction pressure.

Fig. 3b shows the effect of the inlet, or entry, diameter on the die pressure. The figure shows that for a specified diameter of the briquette, a larger inlet diameter will increase the die pressure. Consequently, it can be deduced that for a larger die entry diameter, or higher die reduction ratio, a greater pressure will be required to push the material through the die. This is because larger amount of material is pushed through a die with an outlet orifice of specified diameter when the inlet diameter is larger. This will cause a higher resistance to material flow than when a smaller inlet diameter is used which reduces the amount of material required to flow through the die.

### 3.2. Effects of parameters on the frictional die pressure at the die entry

The effect of friction coefficient on the frictional die pressure at the conical die entry is shown in Fig. 4a. From the figure, it is observed that for specified inlet and outlet diameter of the die entry, the die pressure due to friction reduces with an increase in

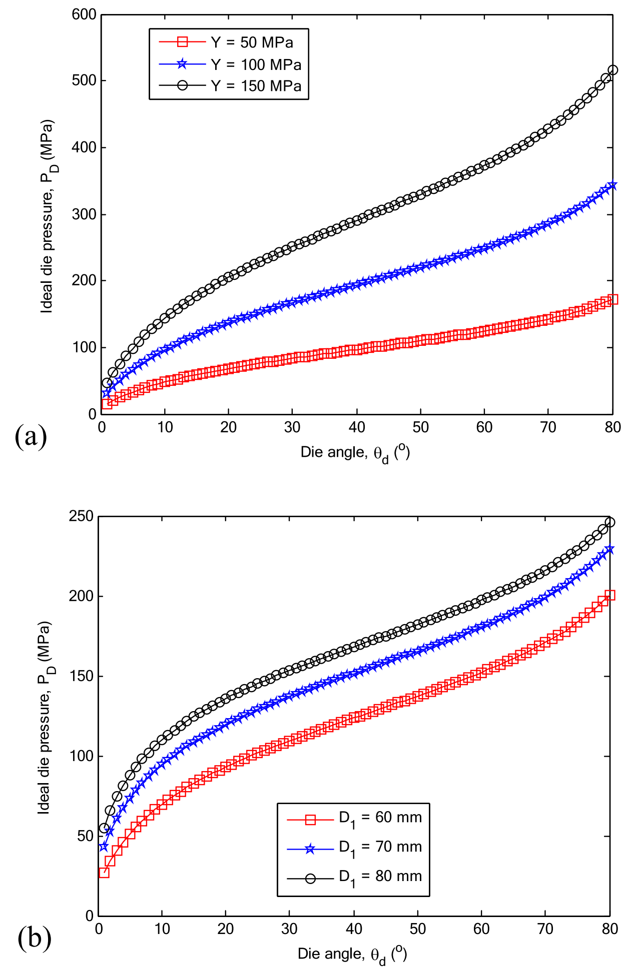


**Fig. 3.** (a) Effect of the yield strength of compacted biomass material on the ideal die pressure; (b) Effect of the inlet diameter of the die of the briquetting machine on the ideal die pressure.

the die angle. This is because of a reduced contact length at the interface of the compacted biomass and the die. It is also observed, as expected, that an increase in the friction coefficient between rubbing surfaces leads to an increase in the die pressure required to extrude the compacted biomass.

Fig. 4b shows the effect of the inlet diameter of the die entry on the extrusion pressure of the die. It is shown that, for a specified diameter of briquette, the frictional die pressure increases with increase in inlet diameter of the die. For specific die entry angle, friction coefficient and briquette diameter, increasing the die entry diameter will result in an increase in the die entry length. This, consequently, increases the rubbing length which is the interface between the compacted material and the die. The increase results in the increase in die pressure.

### 3.3. Optimum die entry angle

It is important to determine the optimum die entry angle for application in the screw extruder biomass briquetting machine. The optimum die entry angle is the angle at which the pressure required to push the compacted material through the briquetting die is minimum. As previously observed, the ideal die pressure increases with an increase in die angle while the frictional die pressure decreases with increasing die angle. An optimum die angle, given parameters of operation, needs to be determined to ensure the minimum pressure for the extrusion. Fig. 5 shows plots to

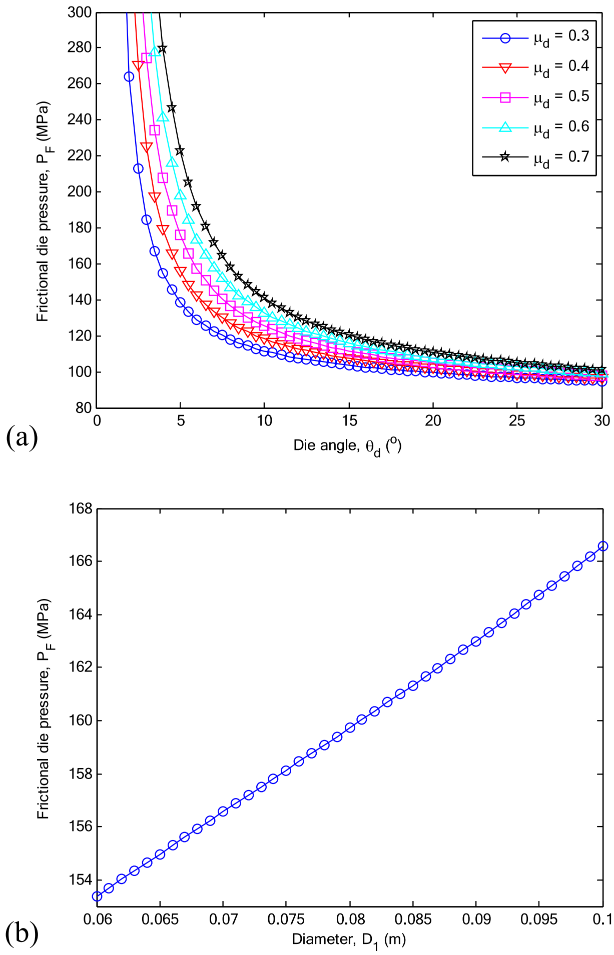


**Fig. 4.** (a) Effect of friction coefficient on the frictional pressure of the extrusion die; (b) Effect of the inlet diameter on the frictional pressure of the extrusion die.

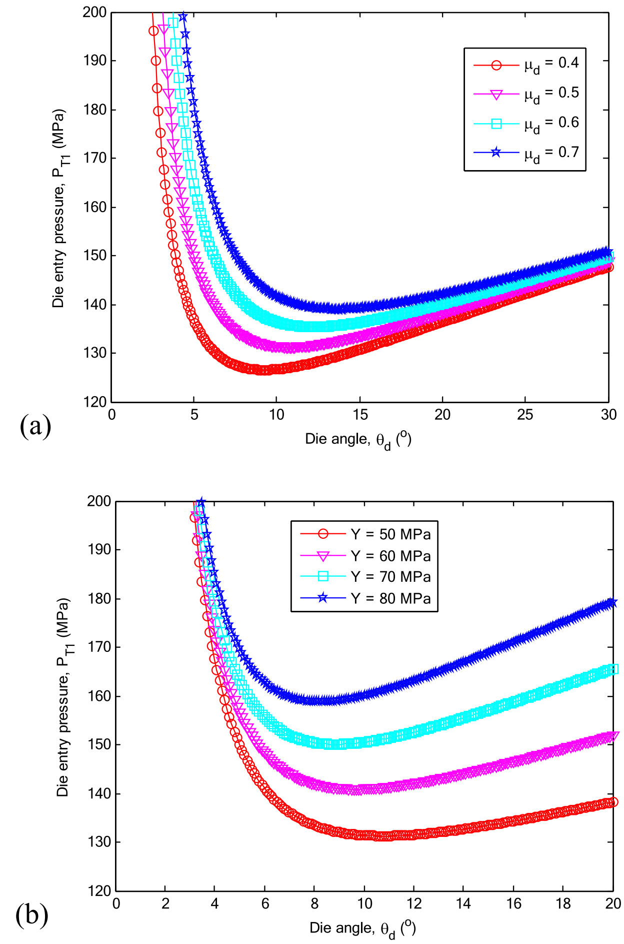


**Fig. 5.** (a) Determination of the optimal briquetting die angle for different friction coefficients between surfaces of compacted biomass and die; (b) Determination of the optimal briquetting die angle for different compacted biomass yield strength.

determine the optimal die angle of a briquetting die. The plots consider both the ideal and frictional die pressures. It is observed from the figures that there is a minimum die extrusion pressure for specified operational, material and geometric parameters.

From Fig. 5a, it is seen that the friction coefficient between the interface of the compacted biomass and the die affects the optimal die angle. The optimum die angle is observed to increase with increase in the frictional coefficient. A higher pressure is required at the optimum die angle when a higher friction coefficient exists between compacted material and the die.

As earlier noted from a study by Mitchual et al. (2013), the strength of briquettes is a function of the species of the biomass material, particle size and compaction pressure. Fig. 5b shows the plot to determine the optimal die angle for compacted biomass materials which have different yield strengths. It is observed that compacted biomass material with higher yield strength requires a smaller optimal die angle.

### *3.4. Effects of parameters on the extrusion pressure at the briquetting die*

The effect of friction coefficient and length of the cylindrical briquetting die on the die pressure is discussed in this section. As observed from Fig. 6a, the briquetting die pressure increases with increasing length for a fixed diameter. In essence, and as shown in Fig. 6b, the die pressure increases with an increase in the length-to-diameter ratio of the die. The reason is because the contact surface between the compacted material and the briquetting die is increased with increasing length. A higher pressure will, therefore, be required to push the material through the longer briquetting die. It is also observed from Fig. 6a that the briquetting die pressure increases with an increase in friction coefficient. This because a greater force, or pressure, is required to overcome higher friction at the contacting surfaces.

## 4. Conclusion

In this study, mathematical models for the study of the die pressure of the screw extruder biomass briquetting machines were developed. Plug flow of material through the die was assumed. The effects of geometrical, material and operational parameters on the pressure at the die entry and the briquetting die were investigated. The optimum die entry angle was dependent on the yield strength of the compacted material passing through the die and also on the friction coefficient at the interface between the die and the compacted material. Increase in the friction coefficient, yield strength, die angle and inlet diameter resulted in increase in the die entry pressure. Increase in friction coefficient and briquetting die length also resulted in increase in the die pressure. The observations from this study contribute to analyses required for development of improved screw extruder biomass briquetting machines.

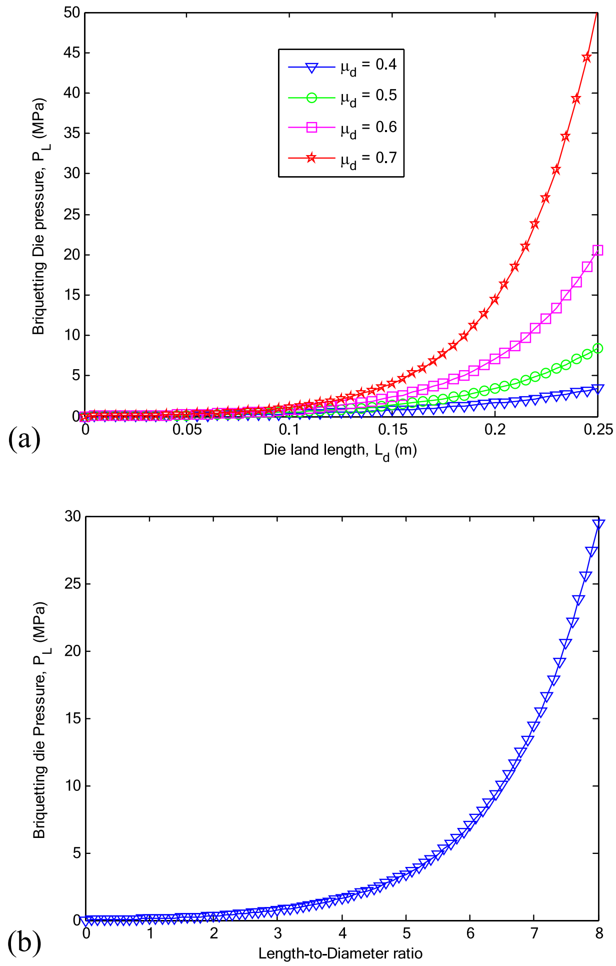


**Fig. 6.** (a) Effect of friction coefficient on the briquetting die pressure; (b) Effect of length-to-diameter ratio of briquetting die on the briquetting die pressure.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References


Babu, D., Yuvaraj, N., 2001. Biomass densification-a solid (fuel) solution. TERI Newswire, 7.

Behravesh, A.H., Shakouri, E., Zolfaghari, A., Golzar, M., 2010. Theoretical and experimental study on die pressure prediction in extrusion of Wood-Plastic Composite. J. Compos. Mater. 44 (11), 1293–1304. https://doi.org/10.1177/0021998309352703.

Dieter, G.E., 1988. Mechanical Metallurgy. McGraw Hill, London.

Ennis, B.J., Witt, W., Sphar, D., Gommerran, E., Snow, R.H., Raymus, G.J., Lister, J.D., 2008. Solid-solid operations and processing. In: Maloney, J.O. (Ed.), Perry's Chemical Engineering Handbook. 8th ed. McGraw-Hill, USA.

Gabriele, D., Curcio, S., de Cindio, B., 2001. Optimal design of a single-screw extruder for liquorice candy production: a rheology based approach. J. Food Eng. 48, 33–44. https://doi.org/10.1016/s0260-8774(00)00140-0.

Jekayinfa, S.O., Scholz, V., 2009. Potential availability of energetically usable crop residues in Nigeria. Energy Sources Part A 31 (8), 687–697. https://doi.org/10.1080/15567030701750549.

Kaygusuz, K., Türker, M.F., 2002. Biomass energy potential in Turkey. Renew. Energy 26 (4), 661–678. https://doi.org/10.1016/s0960-1481(01)00154-9.

Kováčová, M., Matúš, M., Križan, P., Beniak, J., 2014. Design theory for the pressing chamber in the solid biofuel production process. Acta Polytech. 54 (1), 28–34. https://doi.org/10.14311/ap.2014.54.0028.

Lipinsky, E.S., Arcate, J.R., Reed, T.B., 2002. Enhanced wood fuels via torrefaction. Fuel Chem. Div. Prepr. 47 (1), 408–410.

Matúš, M., Križan, P., Ondruška, J., Šooš, L., 2011. Analysis of tool geometry for screw extrusion machines. J. Appl. Math. 4 (2), 404–414.

Mitchual, S.J., Frimpong-Mensah, K., Darkwa, N.A., 2013. Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes. Int. J. Energy Environ. Eng. 4 (1), 1–6. https://doi.org/10.1186/2251-6832-4-30.

Moreira, R., 2006. Global biomass energy potential. Mitigation Adapt. Strategies Global Change 11 (2), 313–333. https://doi.org/10.1007/s11027-005-9003-8.

Mulji, N.C., Mackley, M.R., 2004. Flow field determination during slit extrusion of solid chocolate. Int. J. Form. Processes 7 (3), 375–386. https://doi.org/10.3166/ijfp.7.375-386.

Ojolo, S.J., Ajiboye, J.S., Orisaleye, J.I., 2015. Plug flow analysis for the design of the compaction region of a tapered screw extruder biomass briquetting machine. Agric. Eng. Int.: CIGR J. 17 (3), 176–195.

Ojolo, S.J., Orisaleye, J.I., 2010. Design and development of a laboratory scale biomass gasifier. J. Energy Power Eng. 4 (8), 16–22.

Ojolo, S.J., Orisaleye, J.I., Ismail, S.O., Abolarin, S.M., 2012a. Technical potential of biomass energy in Nigeria. Ife J. Technol. 21 (2), 60–65.

Ojolo, S.J., Orisaleye, J.I., Ismail, S.O., Odutayo, A.F., 2012b. Development of an inverted downdraft biomass gasifier cookstove. J. Emerging Trends Eng. Appl. Sci. 3 (3), 513–516.

Omer, A.M., 2005. Biomass energy potential and future prospect in Sudan. Renew. Sustain. Energy Rev. 9 (1), 1–27. https://doi.org/10.1016/j.rser.2003.12.011.

Orisaleye, J.I., 2016. Analysis and Design of a Screw Extruder Biomass Briquetting Machine PhD Research Seminar II Report. Mechanical Engineering Department, University of Lagos, Nigeria.

Orisaleye, J.I., Ojolo S.J., in press. Mathematical Modelling of Pressure Distribution along the Die of a Biomass Briquetting Machine, International Journal of Design Engineering.

Orisaleye, J.I., Ojolo, S.J., 2019. Parametric analysis and design of straight screw extruder for solids compaction. J. King Saud Univ. Eng. Sci. 41, 86–96. https://doi.org/10.1016/j.jksues.2017.03.004.

Orisaleye, J.I., Ojolo, S.J., Ajiboye, J.S., 2019. Pressure build-up and wear analysis of tapered screw extruder biomass briquetting machines. Agric. Eng. Int.: CIGR J. 21 (1), 122–133.

Yokoyama, S.Y., Ogi, T., Nalampoon, A., 2000. Biomass energy potential in Thailand. Biomass Bioenergy 18 (5), 405–410. https://doi.org/10.1016/s0961-9534(00)00004-0.

Zhong, Z., 1991. Theoretical and Experimental Analysis of the Compaction Process in a Tapered Screw Press. The University of Newcastle upon Tyne. Doctor of Philosophy thesis.

Zolfaghari, A., Behraveh, A.H., Shakouri, E., Soury, E., 2010. Flow balancing in die design of wood flour/HDPE composite extrusion profiles with consideration of rheological effect. Polym. Eng. Sci. 50 (3), 543–549. https://doi.org/10.1002/pen.21567.