Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XLV
Broj 3, 2020.
Strane: 53 – 69

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XLV
No. 3, 2020.
pp: 53 – 69

UDK: 631.3:621.796.2:633.851

Originalni naučni rad
Original scientific paper
doi: 10.5937/PoljTeh2003053O

DEVELOPMENT OF A SINGLE SCREW EXTRUDER FOR THE PRODUCTION OF WOOD-PLASTIC COMPOSITE

Temidayo Omoniyi[*1], Dare Adesanya[2]

[1,2] *University of Ibadan, Faculty of Technology,*
Wood Products Engineering, Ibadan, Nigeria

Abstract: This study was carried out to design, fabricate, assemble and evaluate the performance of a laboratory scale wood-plastic composite (WPC) single screw extruder that can be used for recycling wood and plastic waste materials using locally sourced materials based on availability, strength and cost effectiveness. The extruder is separated into four units; the feeding, conveying, heating and forming unit. The designed parts were; the hopper capacity, the shaft diameter, the screw dimensions (pitch, helix angle and diameter), and the capacity on the conveyor (feed throats, compression and metering units) units. The developed machine was evaluated by using it in extruding low density plastic wastes and gmelina (*Gmelina arborea)* sawdust. The results showed a hopper capacity of 38.3m^3, shaft diameter of 60mm, screw dimensions (diameter=20mm, pitch=50mm, and helix angle = 17.65^0). The performance evaluation of the machine indicated an efficiency of 85% for the machine at an operating speed of 268rpm (4.5rps) with a throughput of 17.55kg/hr during a maximum period of 5 minutes. The mean water absorption (0.45-13.68%) and thickness swelling (0.14 – 0.94%) observed for the composites produced compared favorably with those reported in literature for WPCs recommended for non-structural indoor application purposes. The wood contents and soaking period had effects on the sorption properties and not the effectiveness or ineffectiveness of the machine. The machine conserves cost and energy due to low specific mechanical energy consumption of 191.21kJ/kg.

Key words*: Wood-Plastic Composite, Single Screw Extruder, Renewable Materials, Efficiency, Capacity, Specific Mechanical Energy*

---

[*] Corresponding Author. E-mail: temidayoomoniyi@gmail.com

INTRODUCTION

Industrial logging and exploitation of the world's primary forest are rapidly destroying the habitats of animal and plant species which in turn lead to the depletion of the earth's ozone layer [1]. The destructive exploitation of hardwoods is also responsible for this widespread deforestation.

Wood based-industries generate sawdust from sanding, cutting, drilling and milling operations where wood is removed from a finished product. Wood dusts are very fine particles that are generated during sanding or other machining operations; it is often collected in filter bags or dust collectors and the activities of Plastics Manufacturers such as manufacturing, processing, transportation and consumption add stress to the environmental system by accumulating stock of waste [2, 3]. Today, polythene (and polypropylene), a polymer has been put to different use as containers, wrappers, sachets, bags and packages. Its extensive use has resulted in its litter in every nook and cranny of our roads, markets and other non-designated places. This has caused negative impacts on our environment as they are non-biodegradable.

More than thirty years ago, there has been an increasing concern in wood polymer composites and its applications have been growing and expanding. Environmental issues and high demands on lower material costs are the driving forces behind the increasing need of renewable materials. The accumulation of un-managed wastes especially in developing countries has resulted in an increasing environmental concern.

In Nigeria, recycling is highly necessary so as to reduce the volume of waste generated and also to serve as a means to solving environmental degradation problems as these wastes are currently disposed in sanitary landfills or openly dumped into uncontrolled waste pits and open areas. The Environmentalists including the Engineers have been challenged to develop technically reasonable solutions to environmental waste problems.

Wood-plastic composites (WPC) are made up of two main constituents, though both are polymer based, they are very different in structure, performance as well as origin. Polymers are high molecular weight materials whose performance is largely determined by its molecular composition. In WPCs, the polymer matrix forms the continuous phase surrounding the wood component. These polymers are typically low cost commodity polymers which flow easily when heated and allowing considerable processing flexibility when wood is combined with them. Thus due to the low thermal stability of wood, only polymers with processing temperatures lower than 200^{o}C can be used in WPC. These polymers tend to shrink and swell with temperature but absorb little moisture and can be effective barriers to moisture intrusion in a well-designed composite. The most common polymers used are polyethylene (PE), polypropylene (PP) and polyvinylchloride (PVC).

As a result, the objective of this work was to design and construct a single screw extruder machine that can be used to produce Wood-Plastic Composites from wood wastes and plastic that litters and to evaluate the performance of the machine.

Extruder Description

The extruder is an assembly of a screw-shaft system being rotated by a medium speed electric motor. The screw is housed in a heated cylindrical barrel that employs two processing stages, melting and metering, and a vent section to remove volatiles. The material is fed through a gravity hopper. The melting/mixing mechanism is through barrel heating and screw shearing while the extrudate is metered through the breaker plate and die which gives the product its profile. The output rate is directly related to the screw speed: an increase in screw speed will result in an increased throughput. A pulley and v-belt system is attached to an electric motor to control the screw speed which in turn controls the output rate.

MATERIAL AND METHODS

The materials used for the project work were locally sort machine parts for the fabrication of the Single Screw Extruder, and waste water sachets, plastic bottles and sawdust for the performance evaluation.

Design of the Single Screw Extruder

The design of the Single Screw Extruder was adapted from engineering design principles found in literatures and textbooks [4 – 10].

Design Parameters

In order to achieve the set objectives, the extruder is separated into five units i.e. the feeding, conveying, heating, power unit and forming unit as shown in the exploded view of the extruder in fig. 1. Each of this unit performs specific functions.

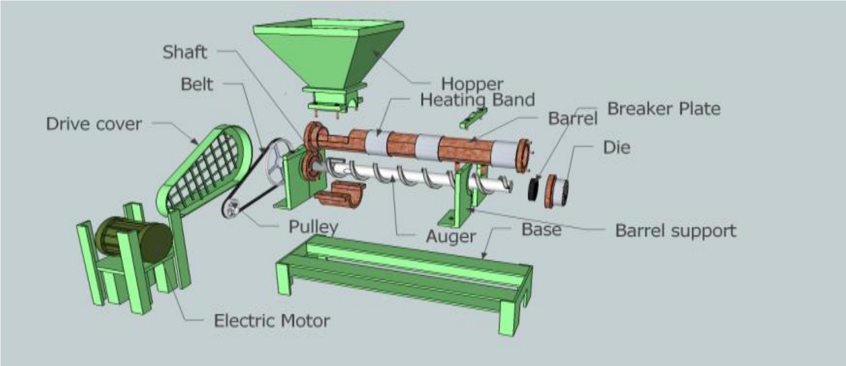


Fig. 1: Exploded view of the Extruder

***Feeding Unit*:** This unit is made up of the hopper, where the materials for processing are fed into the machine and are transported from the top, (inlet), down through the feed throat of the extruder.

The material mixture meets the auger at the feed throat. There are vertical and horizontal forces present in the hopper and act on the inside wall of the hopper.

Therefore, since the operation will be done in batches, the size selected should be considerably small to increase efficiency and also large enough to ensure high production rate.

***Conveying Unit*:** This unit is made up of the screw conveyor also known as the auger. It conveys the mixture that are fed down from the hopper through the feed throat down to the die, with the help of the electric motor, belt and shaft system, passing them through various heating zones. The screw has a pitch of 50mm i.e. the material moves a distance of 50mm in a revolution. The screw also enables mixing required during the process and to generate a stable and homogenous supply of the mixture to the die.

Heating Unit: The heating unit is made of four heating bands wrapped round the body of the barrel and connected to a power source. The heater provides heat to melt the plastic and is set at 180^{o}C to avoid burning the wood content which undergoes thermal degradation at 220^{o}C.

***Power Unit*:** This unit is made up of the electric motor (2hp), V-belt and pulley and the shaft.

Forming Unit: This unit is made up of; the screen pack, the breaker plate, and the die. At this section, the mixture is already in molten form and flows through the screen pack where it is screened to remove impurities and then to the breaker plate which helps to increase the back pressure for proper mixing of the molten and finally to the die which is attached to the extruder through an adapter changing the direction of flow where it takes the final shape.

Design Requirements

The considerations made in the design of the single-screw extruder to enhance effectiveness, safety and affordability include that the power requirement should be minimal, the component should be easy to dismantle, assemble and easily replaced in case of any damage or failure, and the design size will be small-scaled for easy construction at minimum cost and simplicity without compromising standards. The materials of construction used were locally sourced and dependent on suitability, availability, cost effectiveness and strength.

Design Analysis

Assumptions, established theories, principles and engineering equations were used to evaluate the necessary design parameters, strength and size of materials for consideration in the selection of the various machine parts so as to mitigate failure during working span of the machine.

Design of Hopper: The maximum volume of the composite material that the machine can handle in one operation is calculated thus from equation (1).

The top diameter is taken as 3 times the lower diameter [7],

$$V = \frac{1}{3}\pi R^2(H+h) - \frac{1}{3}\pi r^2 H \qquad (1)$$

From Frustum law,

D = 45cm = 0.45m, d = 15cm = 0.15m, h = 50cm = 0.5m

$$\frac{H}{r} = \frac{h+H}{R} = \frac{H}{0.075} = \frac{0.5+H}{0.225}$$

H = 0.25m

$$V = \left[\left(\frac{\pi \times 0.225^2}{3} \times (0.25+0.5)\right) - \left(\frac{\pi \times 0.075^2 \times 0.25}{3}\right)\right] = 0.0383\text{m}^3 \text{ or } 38.3\text{litres}$$

But, volume of hopper = volume of polymer + volume of wood content

Volume of polymer (60% of total volume) = $\frac{60}{100}$ x $0.0383 = 0.023\text{m}^3$

Volume of wood content (40% of total volume) = $\frac{40}{100}$ x $0.0383 = 0.015\text{m}^3$

The mass and weight, of the polymer and wood content to be fed into the hopper, were determined using equation (2) and (3) respectively;

Mass (M) = Density (ρ) X Volume (V) (2)

W = M x g (g= acceleration due to gravity (3)

For plastic, $\text{M}_\text{p} = 530.8\text{kg/m}^3 \times 0.023\text{m}^3 = 12.2\text{kg}$

W_p = 12.2 x 9.81 = 119.68N (W_p = weight of plastic)

For wood, $\text{M}_\text{w} = 112\ \text{kg/m}^3 \times 0.015\text{m}^3 = 1.68\text{kg}$

$\text{W}_\text{w} = 1.68 \times 9.81 = 16.48\text{N}$ (W_w = weight of wood)

Weight of composite = 119.68N + 16.48N = 136.16N

Selection of Electric Motor: An electric motor of the following specification was selected;

Power = 2hp (1.49kw)

Rotational speed = 268rpm

Design of Pulley: In order to achieve the desired speed of the auger, variation of pulley is calculated using the equation (4) of speed ratio reported by Nwaigwe, *et al.* [8],

$$\frac{D_r}{D_m} = \frac{N_m}{N_r} \qquad (4)$$

Where; N_m = rotational speed of electric motor (268rpm) [7].

N_r = rotational speed of rotor

D_r = diameter of rotor pulley (driven pulley, 400mm)

D_m = diameter of motor pulley (driver pulley, 75mm)

$$N_r = \frac{D_m \times N_m}{D_r} = \frac{75\ X\ 268}{400} = 50.25rpm$$

Design of the Belt Drive: Pitch line velocity of the belt was derived from equation (5) given by Khurmi and Gupta, [5];

$$\text{V} = \frac{\pi D N}{60} \qquad (5)$$

Where,

D = Diameter of driver (75mm)

N = Revolutions per minute of the driver (268rpm)

Velocity of the belt, V was calculated thus;

$V = \frac{\pi \times 0.075 \times 268}{60} = 1.05\text{m/s}$

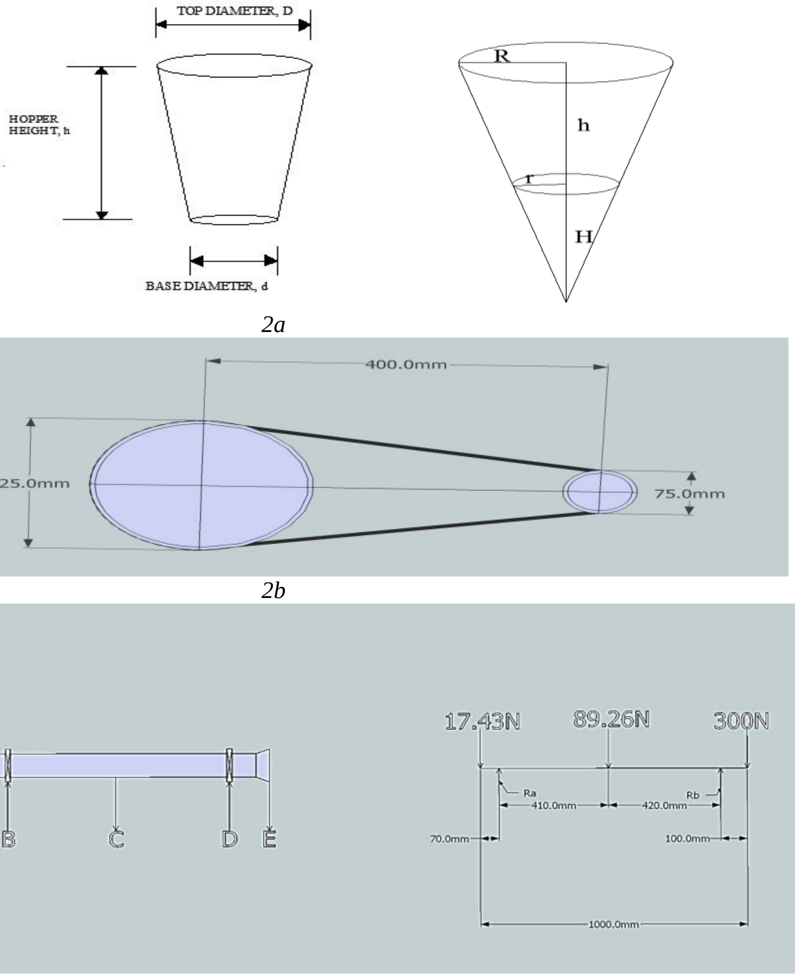
The type of drive belt used was the open belt drive whose length was determined using equation (6) from Khurmi and Gupta [5];

$$L = \pi(r1 + r2) + 2X + \frac{(r1 - r2)^2}{X} \tag{6}$$

Where $r1$ & $r2$ = radius of smaller and larger pulleys (37.5mm, 200mm)

X = distance between the two pulleys (400mm)

$L = \pi(0.0375 + 0.2) + 2(0.4) + \frac{(0.0375 - 0.2)^2}{0.4} = 1.61\text{m}$



2a

2b

2c

Fig. 2.Schematic diagram of the (a) Pulley system, (b) Belt drives, and (c) Shaft of the extruder

Power Transmission: Power transmitted by belt drive was determined using eqns. (7), (8), (9) and (10) in accordance with Khurmi and Gupta [5];

$$P = (T_1 - T_2)\, V\, (watts) \tag{7}$$

Where T_1 = Tension in the belt on the tight side
T_2 = Tension in the belt on the slack side
V = Velocity of the belt
Ratio of driving tension for V-belt drive;

$$2.3\log\frac{T_1}{T_2} = \mu\theta\, cosec\beta \tag{8}$$

Where, μ = coefficient of friction between belt and pulley
θ = angle of contact in radians
β = half of the groove angle (Groove angle, 2β, is usually between 32° to 38° to avoid loss of power due to pulling of belt and excessive wear due to friction and heat) [5].
Let's assume 2β = 34°, therefore β is 17°

$$\sin\alpha = \frac{r_1 - r_2}{X} \tag{9}$$

$\text{Sin } \alpha = \frac{200-37.5}{400} = 0.406$
$\alpha = \sin^{-1}(0.406) = 24°$
Therefore angle of contact is;

$$\theta = (180^\circ - 2\alpha)\frac{\pi}{180}\text{ rad,} \tag{10}$$

$\theta = (180 - 2(24)) \text{ x } \frac{\pi}{180} = 2.3\text{rad}$
The coefficient of friction (μ) between the rubber belt and the dry cast iron pulley is given as 0.3
Assuming power to be transmitted is given as 1.49kw, therefore
$1.49 = (T_1 - T_2)\, 1.05$
$T_1 - T_2 = 1.42$
From equation (8), we have; $2.3\text{Log}\frac{T_1}{T_2} = 0.3 \times 2.3 \times cosec 17°$
$log\frac{T_1}{T_2} = \frac{0.3\times 2.3\times 3.42}{2.3}$
$\frac{T_1}{T_2} = 10^{1.026} = 10.62$
$T_1 = 10.62T_2$
$T_1 = 1.59\text{N}, T_2 = 0.15\text{N}$

Design of the Shaft: The diameter of the shaft (Fig. 2c) was determined using eqns. (11), (12), (13), (14) and (15) in accordance with Khurmi and Gupta [5].

$$T_e = \sqrt{(Km \times M)^2 + (Kt \times T)^2} \quad (11)$$

$$M_e = \frac{1}{2}(Km \times M + \sqrt{(Km \times M)^2 + (Kt \times T)^2}) \quad (12)$$

$$T = (T_1 - T_2)\,R \quad (13)$$

$$T = \frac{\pi}{6} \times t \times d^3 \quad (14)$$

$$M = \frac{\pi}{32} \times \sigma \times d^3 \quad (15)$$

Where, T_e = equivalent twisting or torsion (torque); M_e = equivalent bending moment; M = bending moment; T = torsion or twisting moment; d = minimum diameter required
t = shear stress, 42Mpa for shafts with allowance for keyways [5].
σ = normal stress, 84Mpa for shafts with allowance for keyways [5].
R = radius of bigger pulley (driven pulley)
Using eqns. (11) – (13), the twisting moment to which the shaft is subjected to was determined, given T_1 = 1.59N, T_2 = 0.15N, R = 200mm,
Therefore, T = $(1.59 - 0.15)\ 200$
T = 288Nmm = 0.288Nm

The load is assumed to be uniformly distributed along the effective length of the shaft, which comprises of the weight of the screw and that of the mixture each derived as described by Ugoamadi and Ihesiulor [7]
Weight of screw = 20N
Weight of mixture = 136.16N
Total Weight = 20N + 136.16N = 156.16N
Die weight = 300N

From Fig. 2c,
Weight at point A = Weight of pulley + tension on tight and slack sides = 17.43N
Therefore, $R_b + R_d$ = (17.43 + 156.16 + 300) N
Taking moments at point B,
$R_d \times 0.83 + 17.43 \times 0.07 = 156.16 \times 0.41 + 300 \times 0.93$
R_d = 411.81N and R_b = 61.78N
Weight of the bearings is 411.81N and 61.78N
Resultant bending moment on the screw shaft is given as $M_b = 300N\ x\ 0.93 = 279Nm$

Maximum bending moment on screw shaft is 279 Nm

$$Me = \frac{1}{2}\left(1.5\,X\,279 + \sqrt{(1.5\,X\,279)^2 + (1.0\,X\,0.71663)^2}\right) = 837Nm$$

$$d = \sqrt[3]{\frac{32\,x\,M}{\pi\,x\,\sigma}} = \sqrt[3]{\frac{32\,x\,837}{\pi\,x\,84\,x10^6}} = 0.04665m = 46.65mm$$

$$Te = \sqrt{(1.5\,X\,279)^2 + (1.0\,X\,0.71663)^2} = 418.5Nm$$

$$d = \sqrt[3]{\frac{T\,x\,6}{\pi\,x\,\tau}} = \sqrt[3]{\frac{418.5\,x\,6}{\pi\,x\,42\,x\,10^6}} = 0.0267m = 26.7mm$$

Hence the standard diameter of shaft was chosen as 60mm from the list of available size and a bright mild steel material.

Design of Screw Conveyor: The screw is made up of 3 zones, which are: the feed zone, the compression zone, the metering (pumping) zone. Figure 3 shows a schematic diagram of the zones of the screw.

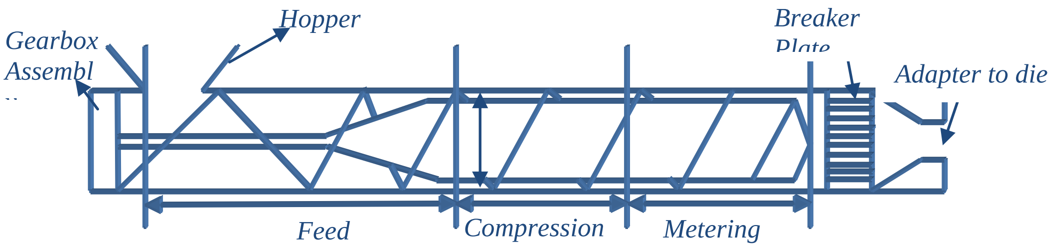


Fig. 3: Schematic diagram of the screw conveyor

According to Anonymous [4], the L/D $\left(\frac{useful\ flight\ lenght\ of\ screw}{screw\ diameter}\right)$ ratio of the screw for thermoplastic extruder ranges from 25:1 to 35:1, and extruders are described according to the outside diameter of their screw ranging from 25mm to 300mm. As a result, an L/D ratio of 30:1 and a screw diameter of 30mm were selected. Hence the flight length of the screw was determined as;

Useful flight height = $\frac{screw\ diameter \times 30}{1} = \frac{30 \times 30}{1} = 900mm$

The flows in the extruder were analysed according to eqns. (16) – (20) described by Anonymous [4] and Oswald and Hernandez [6];

Total flow = Drag flow (Q_d) – Pressure flow (Q_p) – Leak flow (Q_l). (16)

Drag flow (Q_d) = $\frac{1}{2}\pi^2 D^2 N sin\varnothing cos\varnothing H$ (17)

Where,

D = Screw diameter = 50mm
H = Channel depth of screw = $\frac{Internal\ Diameter\ of\ barrel - Diameter\ of\ screw}{2}$
Internal diameter of barrel = 73mm
H = $\frac{73-50}{2} = 11.5mm$
N = Screw rotational speed = 268rpm = 4.5 rps
Ø = Helix angle but Pitch = πDtanØ, pitch = 50mm
Ø = 17.65°

Therefore, Drag Flow is 1.85 x 10^{-4} m^3/s

Pressure flow (Q_p) = $\frac{\pi D H^3 Sin^2\varnothing}{12\eta}\left(\frac{dp}{dl}\right)$ (18)

Where,

dp = Pressure drop along extruder

dl = Length of flow path

$$\eta = \text{Fluid viscosity} = m(T°c)\gamma^{n-1} \quad (19)$$

With, m = Consistency Index = $6 \times 10^3 (Pa - s)^n$

n = Power Law Index; n = 0.39

γ = Shear Rate = $\frac{Velocity}{Channel\ depth} = \frac{1.67 \times 10^{-4}}{3.5 \times 10^{-3}} = 0.048 s^{-1}$

$\eta = 7.6 \times 10^6 pa.s$

Pressure Flow **was found to be 5.54 x 10^{-13} m^3/s**

$$\text{Leak flow } (Q_l) = \frac{1}{12\eta}\frac{\Delta p}{e cos\emptyset}\frac{\pi D}{cos\emptyset}\delta^3 \quad (20)$$

Where, H = δ = Depth of silt

e = width of screw flight

Note: Leak flow is insignificant compared to drag flow and pressure flow and may be neglected in finding total flow

Design of Barrel: An efficient barrel cooling system is important to control the tendency for mechanical shear heat developed in the melt to override the electrical heater controls. The optimal extruder barrel length is 30-32 times its internal diameter (30:1 L/D, 32:1 L/D). Although shorter barrels can be used, but mixing efficiency and melt uniformity may not be optimal. Cooling to the extruder feed throat is provided by a rotating fan to prevent surging or bridging. Internal cooling to the screw is not needed.

Assumptions

The outer diameter and internal diameter of barrel were chosen as **88mm and 73mm** respectively, therefore length of barrel will be 73mm times 32 which is equal to **2336mm.** The thickness of the barrel is 15mm to withstand the escape of heat through the barrel.

Design of Heating Bands: The mixture of the plastic and wood material must be processed at a temperature at or below the thermal degradation of the wood fibres, normally 200 to 220℃ (392 to 428°F), and most plastics are processed between temperatures between 163℃ & 200℃ even though melting can occur between 108 to 121℃ [7, 11]. The target temperature was chosen as 180℃ for the barrel. Hence, the mixture must be raised from room temperature (25℃) to the target temperature (180℃) and the polyethylene material acts as the binding agent in the mixture, it flows when heated allowing proper mixing of the mixture, the heat needed to raise the temperature of the material from 25℃-180℃ was determined using eqn. (21) as described by Ugoamadi Ihesiulor [7];

$$Q_{25°C-180°C} = MC_P\Delta t_1 + ML + MC_P\Delta t_2 \qquad (21)$$

Where, M = Mass of material

C_P = specific heat capacity of polyethylene material (2.004 KJ/Kg.K)

L = Specific latent heat of fusion (74.8 KJ/Kg)

$$Q = 13.88 \times 2.004 \times (121 - 25)°C + 13.88 \times 74.8 + 13.88 \times 2.004 \times (180 - 121)°C$$

Q = 2670.29 + 1038.22 + 1641.12

Q = 5349.63KJ

The heat source must be able to generate this amount of heat and the amount of heat that will be lost through the walls of the heating chamber.

Fabrication and Assembly of the Machine

The single screw extruder parts such as the hopper, the barrel, the stands and the screw were fabricated and assembled at the Faculty of technology technical workshop, university of Ibadan, Ibadan Nigeria. The process undertaken during the operations include, marking out, cutting, beating, sharpening, drilling, boring and welding.

Fabrication and Performance Test the Machine

Following the design, fabrication and assembly of the machine, the performance of the single-screw extruder was evaluated. The machine was prepared for the extrusion operation by first switching on the heater (i.e. the heating element). The heating lasted for 45mins to enable the barrel reach the heating temperature of 180°C. The sorted samples comprising of both plastic and *melina arborea* sawdust at different compositions were fed into the machine through the hopper, as the electric motor was simultaneously switched on. The time taken for recycling per batch was monitored with the use of a stop watch. A 2-Hp-3-phase electric motor was used as prime movers at specific periods of time. The time taken to recycle each quantity of plastic and sawdust varied from 5 to 10 minutes for each of the prime movers, the average performance efficiency and the capacity of the machine were estimated using eqns. (22) and (23) respectively:

$$\text{Performance Efficiency } (\%) = \frac{\text{mass of recovered material}}{\text{mass of input material}} \times 100 \qquad (22)$$

$$\text{Average Capacity of machine } = \frac{\text{mass of input material (kg)}}{\text{time taken for crushing (hr)}} \qquad (23)$$

Five test samples of wood plastic composites (WPC) in the ratio of Plastic/Wood of 90/10, 80/20, 70/30, 60/40, and 50/50, were produced, each in three replicates. The samples of the WPCs produced were cured for 28 days and were weighed to determine the amount of plastic and sawdust that was recycled. The sorption (Water absorption (WA) and Thickness swelling (TS) properties of the WPCs produced were determined using standard procedures. The tests were carried out according to standard methods [12].

Measurements of mass (g), thickness (mm) and length (mm) of the samples were taken prior to treatment as initial parameters while the final measurements were taken after immersion in water for 2h and 24h using electronic weighing balance, digital caliper and meter rule, respectively. The properties were estimated using the following equations (24) and (25):

Water Absorption (WA (%): $$\mathbf{WA}\ (\%) = \frac{W_2 - W_1}{W_1} \times 100 \qquad (24)$$

Thickness Swelling (TS (%): $$\mathbf{TS}\ (\%) = \frac{T_2 - T_1}{T_1} \times \mathbf{100} \qquad (25)$$

Where: W_1, T_1, L_1 are initial mass (g), thickness (mm), and length (mm) before treatment and W_2, T_2, L_2 are final mass (g), thickness (mm) and length (mm) after treatment, respectively.

DISCUSSION OF RESULTS

Performance Evaluation of Extruder Results

The designed Single Screw Extruder was fabricated and assembled as shown in Figure 4. The capacity of the hopper is about 38.3litres, where the materials to be extruded are fed through. When the machine was operated at a speed of 268rpm (4.5rps), the efficiency was found to be 85% with a throughput of 17.55 kg/hr and a low specific mechanical energy of 191.21kJ/kg was achieved as expected to save running cost and high energy consumption.

Operation of the Single Screw Extruder

In agreement with Dhanasekharan and kolini [13], the movement of materials from one chamber to another was hindered by the drag force by the screw. The mechanical behavior of the screw was observed as the fed materials passed through the feed throat to the compression unit where the force of compression splits and meshes granular materials until their surface areas are reduced [14]. The maximum acceleration and kinetic energy of the rotating screw at 4.5rps were observed in the compression unit. This is important, as the effective mixing or homogenization of the granular materials occur at this unit [10]. The materials gained entrance to the metering zone where they acquire enough pressure to pass through the breaker plate and into the die opening of the extruder (forming unit). This corroborates the findings of Jiang and Bi [15] and Siregar *et al.* [16].

Figure 5 shows that the lower the Specific Mechanical Energy (SME) at low speed the higher the output mass. This is as expected, as many output mass can be achieved in a longer period of time at low speed and low kinetic energy thereby leading to a reduced capacity measurement. The results showed that the lowest and highest output mass of 0.76kg and 0.88kg at specific mechanical energy of 450KJ/Kg and 200KJ/Kg respectively. Although the SME reduces with increasing output mass. The use of a lower speed for the operation of the machine will result to an increase in output mass because the loss of the material during operation will be minimal; therefore lower speeds results in lower specific mechanical energy [10].

Figure 4: Fabricated Single Screw Extruder

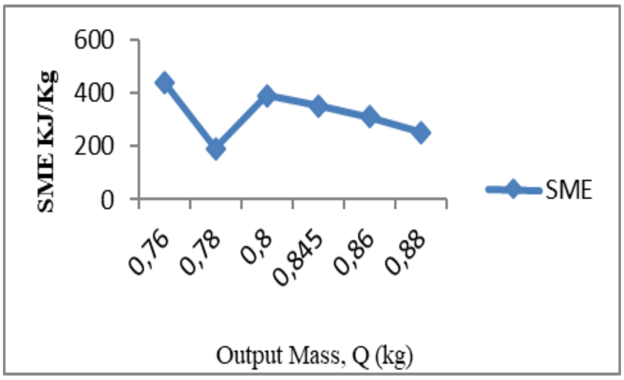


Figure 5: The Effect of Mass Output on the Specific Mechanical Energy under the Influence of Screw Speed and Torque

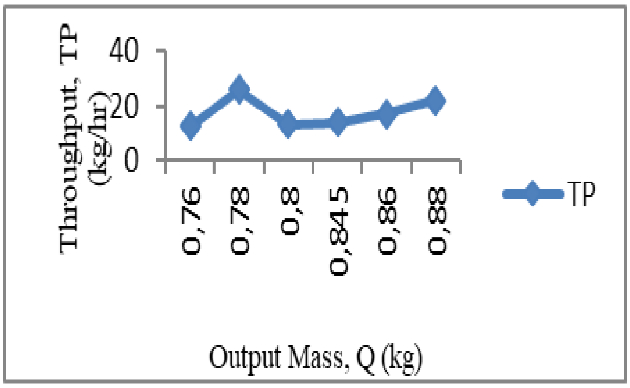


Figure 6: The Effect of the Throughput on the Mass Output of the Machine under the Influence of Screw Speed and Torque

Except for the throughput between the output mass of 0.78kg and 0.8kg (Figure 6), increase in the throughput indicates increase in the output mass provided the operation was carried out over the same length of time.

Wood-Plastic Composite Test

The results of various tests carried out to determine some physical properties of the wood-plastic composite are presented in Tables 1, 2, and 3.

Density and Mass: The volume of each sample was estimated from the nominal dimensions while the mass was determined using a weighing scale. The density of each sample was calculated in g/cm^3. The densities of the WPCs produced are presented in Table 1. The results indicated that the density ranged from $0.35 g/cm^3$ ($350 kg/m^3$) to $0.95 g/cm^3$ ($950 kg/m^3$). Generally, as the wood content in the composite is increased the density of composite produced also increased. This corroborates the findings of Omoniyi and Yinusa [17].

Table 1. Mean Dimensions, Mass and Densities of WPCs Produced

Sample (Plastic/Wood ratio)	***Dimensions** (cm)*			*Diameter (cm)*	*Volume (cm^3)*	*Mass (g)*	*Density (g/cm^3)*
	Length	*Breadth*	*Thickness*				
***A** (90/10)*			*1.4*	*7.5*	*61.88*	*44.00*	*0.711*
***B** (80/20)*	*10.2*	*4.0*	*1.3*		*53.04*	*45.30*	*0.854*
***C** (70/30)*	*10.2*	*3.2*	*1.7*		*55.49*	*47.85*	*0.862*
***D** (60/40)*	*10.5*	*3.2*	*1.9*		*63.84*	*56.01*	*0.877*
***E** (50/50)*	*11.4*	*3.9*	*1.7*		*95.68*	*68.55*	*0.907*

Thickness Swelling (TS)

Table 2 shows the increase in thickness of the samples when soaked in water at 0h, 2h and 24h. The mean TS values ranged from 0.14 – 0.94%. Sample A has the lowest TS value while sample E has the highest value. It can be observed from the results that wood contents increased the TS also increased which may be due to the hydrophilic nature of wood. However, the TS values compared favorably with the 0.12 – 4.05%, reported by Oluyege *et al.* [18] for the TS values observed for WPCs produced from *Ceiba Pentandra* particles.

Table 2. Thickness Swelling (%) of WPCs Produced

Sample (Plastic/Wood ratio)	*Thickness (mm)*			*Thickness Swelling (%)*	
	0hr	*2hrs*	*24hrs*	*After 2h*	*After 24h*
A(90/10)	*14*	*14.02*	*14.04*	*0.14*	*0.29*
B(80/20)	*13*	*13.02*	*13.05*	*0.15*	*0.38*
C(70/30)	*17*	*17.04*	*17.10*	*0.24*	*0.59*
D(60/40)	*19*	*19.07*	*19.17*	*0.37*	*0.89*
E(50/50)	*17*	*17.07*	*17.16*	*0.41*	*0.94*

Table 3. Water absorption (%) of WPCs Produced

Sample (Plastic/Wood ratio)	*Weight (g)*			*Water absorption (%)*	
	0hr	*2hrs*	*24hrs*	*After 2hrs*	*After 24hrs*
A(90/10)	*44*	*44.2*	*44.70*	*0.45*	*1.59*
B(80/20)	*43*	*43.3*	*43.80*	*0.70*	*1.86*
C(70/30)	*42.25*	*43.05*	*43.31*	*1.89*	*2.51*
D(60/40)	40	42.4	44.10	6.00	10.25
E(50/50)	38	40.25	43.20	5.92	13.68

Table 3 presents the WA for the WPCs produced. From the results presented, the WA values ranged from 0.45 – 13.68%. Sample A, which contains 10% sawdust of *melina arborea* in its components has the lowest value for WA while the highest value was observed for sample E with 50% wood fibre contents. Although other samples have low water absorption, however, there are significant differences in the (2h) and (24h) periods of soaking. The results also indicated that as the wood content increased in the mixing ratio, the WA also increased. Water absorption of composite is an important factor in classifying its durability and composites of low water absorption will afford better protection to reinforcement within it [19].

The WPCs produced where smooth in appearance and insignificant coarseness only felt and may not be visible. This implies a proper blend and mixture of the granular materials by the machine indicating the effectiveness of the machine designed and fabricated. It can be inferred from the findings that the sorption (WA and TS) properties of the WPCs produced were as a result of the components mixed and the time of soaking and not as a result of the machine fabricated.

CONCLUSION

The need to reduce the effects of environmental pollution by plastic materials littering the surroundings and wood wastes materials used as landfills or burnt causing green-house effects, brought about the implementation of the idea to design and fabricate a laboratory scale single screw extruder that can be used to turn these wastes to wealth. The design and fabrication of the machine was successfully carried out and the performance evaluated. The performance test showed the machine had an efficiency of 85% and an output capacity of 17.55kg/hr. The WPC produced using the extruder showed sorption properties which compared favorably with some reported in literature for WPCs recommended for indoor applications. Hence the designed aim of the study has been achieved by designing and fabricating a single screw extruder which can be used for recycling waste pure water sachets, plastic bottles and wood wastes (sawdust).

REFERENCES

[1] Einwood, 2010. Wood plastic composites: a material of the future.
[2] Maiju Hietala. 2011. Extrusion Processing of Wood Raw Materials for Use in Wood-Polymer composites. Lulea Univ. of Technology, Lulea, Swden. pp.1-18.

[3] Brandrup J., 1996. Recycling and recovery of plastics. Hanser Publisher Verlag. ISBN-10:3446182586. pp.1-927.

[4] Anonymous ,1955. Description and analysis of polymer flow in extruders. http:// www.kmutt.ac.th/p-prof/P-PROF%2520w... Assessed on 28/04/2020.

[5] Khurmi, R.S., and Gupta, J.K., 2005. A Text Book of Machine Design, Eurasia Publishing House (PVT) Ltd. India, pp 1-1251

[6] Oswald, T. and Hernandez, J.P. 2006, *Polymer Processing – Modeling and Simulation*, Polymer Processing – Modeling and Simulation, 1st Edition. Munich Hanser Verlag.

[7] Ugoamadi C.C. and Ihesiulor O.K, 2011. Optimization of the development of a plastic recycling machine. *Nigerian Journal of technology*, Vol 30, No 3.

[8] Nwaigwe K.N, Nzediegwe .C, Ugwuoke P.E., 2012. Design, Construction and Performance Evaluation of a Modified Cassava Milling Machine. Research Journal of Applied Sciences, Engineering and Technology 4(18): 3354-3362.2012 ISSN: 2040-7467, © Maxwell Scientific Organization, 2012.

[9] Odior A.O., Oyawale Festus A. and Odusote Joe K., 2012. Development of a polythene recycling machine from locally sourced materials. Industrial Engineering Letters, ISBN 2225-0581 (online), Vol 2, No. 6, 2012. Pp 42 – 46

[10] Fadeyibi, A., Osunde, Z.D., Agidi, G., and Egwim, E.C., 2016. Design of Single Screw Extruder for Homogenizing Bulk Solids. *Agricultural Engineering International: CIGR Journal*, 18(4), 222-231

[11] Wood Handbook 2010. Wood as an Engineering material, April 2010

[12] ASTM D570, 2018. Standard Test Method for Water Absorption of Plastics. West Conshohocken: ASTM

[13] Dhanasekharan, K..M., and Kokini, J.L., 2003. Design and scaling of wheat dough extrusion by numerical stimulation of flow and heat. *Journal of food Engineering*, *60*(4), 421-430

[14] Petrou, M., Novak, O., Hera, D., and Simanjuntak, S., 2012. Finite element method model of the mechanical behaviour of *Jatropha curcas* L. seed under compression loading. *Biosystems Engineering*, 111(1), 412-430

[15] Jiang, B., and Bi, C. 2009. Study of residence time distribution in a reciprocating single screw pin-barrel extruder. *Journal of Materials Processing Technology*, 209(8), 4147-4153.

[16] Siregar, N.A., Mamhood, W.M., Ghani, J.A., Haron, C.H., and Rizal, M. 2014. Design and Analysis of Single Screw Extruder for *Jathropha* Seeds Using Finite Element Method. *Research Journal of Applied Sciences, Engineering and Technology*, 7(10), 2098-2105.

[17] Omoniyi, T.E., and Yinusa, R.O. 2018. Development of Processing Equipment for Souvenir Production from Wood and Plastic Wastes. *Proceeding of 6th NSCB Biodiversity Conference Uniuyo*, 2018, 390-386.

[18] Oluyege, A., Ekong, A., Aguda, L., Ogunleye, B., Abiola, J., and Olayiwola, Y. 2017. Physical and Mechanical Properties of Wood Plastic Composites Produced from Sawdust of *Ceiba pentandra* (L.) Gaerten. and Plastic Wastes. *Journal of Forestry Research and Management, 14*(2), 95-112.

[19] Omoniyi, T.E., Akinyemi, B.A., and Fowowe, A.O. 2014. Effects of Waste Glass Powder as Pozzolanic Material in Saw Dust Cement Brick. *Scholars Journal of Engineering and Technology (SJET)* 2(4A), 517-522.

RAZVOJ EKSTRUDERA SA JEDNIM VIJAKOM ZA PROIZVODNJU DRVENO-PLASTIČNOG KOMPOZITA

Temidayo Omoniyi[1] and Dare Adesanya[2]
[1,2] University of Ibadan, Faculty of Technology,
Wood Products Engineering, Ibadan, Nigeria

Sažetak: Ova studija prikazuje projektovanje, proizvodnju, sastavljanje i procenu performansi mašine ekstrudera sa jednim vijakom za drvno-plastične materijale (WPC) koji se može koristiti za reciklažu drvnog i plastičnog otpadnog materijala koristeći ove materijale iz lokalnih izvora, na osnovu raspoloživosti i isplativosti.

Ekstruder ima četiri celine-jedinice predviđene za: prijem materijala, transport, zagrevanje i oblikovanje. Dizajnirani delovi su: kapacitet prijemnog koša, prečnik pužne osovine, dimenzije vijka (korak, ugao i prečnik zavojnice pužnog elementa) i kapacitet transportera (jedinica za dovod, kompresiju i doziranje). Razvijena mašina je procenjena kod upotrebe u ekstrudiranju plastičnog otpada male gustine i piljevine stable biljke gmelina (*Gmelina arborea)*. Rezultati su dobijeni za kapacitet prijemnog koša od 38,3 m^3, prečnik osovine od 60 mm, i dimenzije pužnog vijka (prečnik = 20 mm, korak=50 mm i ugao zavojnice = $17,65^0$).

Procena performansi mašine pokazala je efikasnost od 85% za mašinu pri radnoj brzini od 268 o/min (4,5 o/min) sa protokom materijala d 17,55 kg/sat za maksimalni period od 5 minuta. Srednja adsorpcija vode (0,45-13,68%) i porast debljine (0,14 - 0,94%) zabeleženi su kod proizvedenih kompozita i upoređeni su povoljno sa onima koji su u literaturi navedeni za WPC preporučene materijale. Sadržaj drveta i period kvašenja uticali su na adsorpciona svojstva, a ne na efikasnost ili neefikasnost mašine.

Mašina štedi troškove i energiju zahvaljujući niskoj specifičnoj potrošnji mehaničke energije od 191,21 kJ/kg.

Ključne reči: *kompozit od drveta i plastike, ekstruder sa jednim vijkom, obnovljivi materijali, efikasnost, kapacitet, specifična mehanička energija.*

Prijavljen:
Submitted: 27.05.2020.
Ispravljen:
Revised: 20.07.2020.
Prihvaćen:
Accepted: 15.09.2020.