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Development and Testing of Screw Type Kenaf *(Hibiscus Cannabinus)* Pelletizing Machine

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Abstract The screw type pelletizing machine was designed and fabricated using locally available construction materials to make handling and packaging of ground Kenaf fibres easy for onward utilization as a tool for remediating oil spilled water bodies. The machine was designed to be portable for easy transportation and to be operated by an individual and pelletizing was achieved through the process of extrusion and bonding of ground kenaf powder with the aid of binding agents (starch, cissus gel and animal feed). Main features of the machine are gearbox, electric motor (3 phase, 5 hp rating), 40mm axial shaft, screw auger, extrusion barrel, bearing case, pulley, chain and sprockets, the dimension of the machine frame is (900 × 550 × 700 mm). The performance of the machine was based on pelleting efficiency, percentage recovery and throughput capacity of the machine, which were determined at three different particle sizes using three organic binders. Pelleting efficiency ranged between 82.22 - 86.87%, 79.14- 82.45% and 89.87 - 93.54% for Cissus, Starch and Animal Feed binders respectively. Percentage recovery of the machine ranged between 86.29 - 91.11%, 85.0 - 90.61% and 90.23 - 94.03% for Cissus, Starch and Animal Feed respectively while the throughput of the machine ranged between 32.72-35.49 Kg/hr, 33.79-34.77*Kg/hr* and 36.82 - 37.88*Kg/hr* for Cissus, starch and Animal feed respectively. The machine performance was satisfactory as the pellets produced could be used in absorbing oil from oil spilled water bodies.

Keywords: Screw, pelletizing machine, Kenaf, oil absorption, binders, particle size

Introduction

Kenaf (*Hibiscus cannabinus*) is a fibre crop closely related to okra and sunflower. Kenaf has being utilized for over six millennia as cordage, food, oil source, paper making, insulation (Han *et al.*, 1999). Though, it was initially domesticated in Eastern Africa, the place of origin of the Kenaf plant has over the years being in speculation. Kenaf is a conventional crop similar to maize that requires lesser attention with little or no fertilizer application within a wide range of climatic conditions dependent of the species planted. Kenaf can grow

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to a height of 1.5-3m, reaching maturity within a time span of 3-4 months (Le Mahieu *et al.*, 1991; Webber *et al.,* 2002; Princen, 1982; Dempsey, 1975; Euchora, 2004; Seale *et al*., 1996).However, recent studies have shown that as a natural polymer, Kenaf fibres just like other porous materials such as cotton can also be used in bioremediation of oil spilled water bodies (Cai *et al.*, 2010; Dyke and Reed, 2010; Karan *et al*., 2010; ASAE, 2010).

Kenaf Characteristics

Further studies have actually proved that Kenaf bast and core fibres tends to absorb more oil than the fibre strands as used by Dyke and Reed, 2010, however, there is need to reduce sizes of the fibres to facilitated larger surface to volume ratio that will increase the volume of oil absorbed within a short period of time. The reduced Kenaf fibres should also be moulded to make handling and packaging easier as powdery fibres may be difficult in application to affected water bodies. Size reduction can be done using a wide range of milling machines, some of which are ball mill, hammer mill, Roller mill, attrition mill, knife mill and pin mill (Nwaigwe *et al*., 2012; Nasir, 2005, Too *et al*., 2012; Dissanayake *et al*., 2006).

Pelletizing can be achieved using extrusion machines which include the rotary pelletizer, the screw type and the hydraulic press however, the most widely used method is the screw type in which the raw materials oil are pressed in a perforated chamber. Fellows (2000) reported that the screw type method generally consist of the screw conveying system, cylindrical barrel and the die and it can also be incorporated into extruders and it is easier to operate and maintain as the machinery cost is lower when compared to the rotary pelletizer.

The objective of this study is to present a design that encompasses size reduction as well as extrusion using the screw type pelletizing method.

The screw type pelletizer comprises an axial chamfered shaft that runs through the machine, the shaft had an auger fitted on it, the auger was fabricated using a hollow circular 45mm plate with an internal diameter of 25mm, the plates were slit and welded along the shaft to form a power screw, the power was right threaded to make pelletizing occur in a clockwise direction, this is similar to the pelletizer constructed by Davies and Davies (2010). A typical kenaf plant is shown in plate 1.

Plate 1. A Typical kenaf plant

Machine Design and Fabrication

The materials utilized in the fabrication of the screw type pelletizing machine are: a chamfered shaft, pulleys, belts, conical bearings, cone, Gearbox, angle bars, cylindrical pipes, steel plates sprocket, double chain link, flanges and Electric Motor.

Design Considerations

The screw type pelletizer is to be used along with a plate mill that will reduce decorticated stems into smaller sizes that can be extruded thus pelletizer will use the same power source for the grinder. In designing the machine, Engineering properties of Kenaf stems was used, it was obtained from Seale *et al*., 1996, the crushing pressure of Kenaf was within the range 682-1200kPa. The plate mill is to be fitted such that the output from the plate mill is fed directly into the pelletizer, thus the system and hopper capacity will be that of the plate mill.

The following were taken into consideration during the design of the machine: System Capacity, Hopper Capacity, Power Requirement, Forces acting on the shaft, Diameter of the shaft

Design Analysis

System Capacity: Hall (1972) reported the system capacity for fibrous crops such as oats as 6.6*Bu/hr* (0.23276m^3/hr) but the density of Kenaf is 218 Kg/m^3 (Seale *et al*., 1996); thus, the mass of Kenaf consumed per hour will now be 218 $\times$0.23276 = 50.74168 Kg/hr.

Hopper Capacity: The machine is required to be portable, a hopper capable of being emptied every minute is chosen, and the volume of the hopper is mathematically expressed as:

$$V_H = \frac{C_M\left(m^3/hr\right)}{N_C\left(\min/hr\right)} \qquad (1)$$

$$V_H = \frac{0.2327\left(m^3/hr\right)}{60\left(\min/hr\right)} = 3.8793 \times 10^{-3} m^3$$

A factor of safety is also needed in the design, assuming a F.S. of 1.5, the hopper capacity now becomes $1.5 \times 3.8793 \times 10^{-3} m^3 = 5.819 \times 10^{-3} m^3$

Power Requirements: The pelletizer will be running on the same source of power with the plate mill and the power required for the running the plate mill is classified into two. These are:

Power used in Conveying Kenaf

According to (Olofin, 2006), the power used in conveying Kenaf is given by the formula $P = \left(ALN + QLF\right) \times 10^{-6}$ (2)

P is the power at the conveyor head shaft (HP), A is the Factor for Conveyor Size, Q is the Quantity of Material to be Conveyed (*Lb. /Hr.*), L = Length of the Conveyor (*Ft.*), N = Angular Speed of Conveyance (rpm), F = Factor of Material Conveyed

For this design, A= 3.81, Q = 111.8662*Lb*, L = 0.6562*ft*, F = 6.0

$P = \left(\left[3.81 \times 0.6562 \times 800\right] + \left[111.8662 \times 0.6562 \times 6.0\right]\right) \times 10^{-6} = 0.00244$ HP

Power Consumed in Crushing Kenaf

Power is the product of Torque and Speed, but Torque is Force × Diameter

However, Force is Pressure × Area

Area is given by the formula $A = \frac{\pi\left(D_{EX}^2 - D_{IN}^2\right)}{4}$ (3)

Where D_{Ex} is external diameter of the auger and D_{In} is the internal diameter of the auger on the shaft

For this design, D_{Ex} = 45mm (0.045m), D_{In} = 25mm (0.025m)

For this design, Pressure is 1200 kPa, (the particles are desired as small as possible) $F = \frac{P \times \pi\left(D_{EX}^2 - D_{IN}^2\right)}{4}$ (4)

$F = \frac{1.2 \times 10^6 \times \pi \times \left(0.045^2 - 0.025^2\right)}{4}$ = 1319.469 *N*

But Torque = Force × D_{Av}, where D_{Av} = 0.5 × (D_{Ex} + D_{In}) = 0.035m

Torque, T = 1319.469N ×0.035m = 39.58407 *Nm*

Also Power = Torque × Angular Speed

Angular speed is obtained by the formula $\omega = \frac{2 \times \pi \times N}{60}$ (5)

where N is the speed of the shaft in rev/min

For this design N = 800 *rpm*

$\omega = \frac{2 \times \pi \times 800}{60}$ = 83.776 *rad/s*

But Power = Torque × Speed= 39.58407× 83.776 = 3316.187W ≈ 4.445HP

Total power consumed =- 4.445 + 0.00244 = 4.44744HP ≈ 5HP

Transmission Design

Gearbox Selection

Motor Speed = 1440 *rpm*

Design Speed= 80 *rpm*

Reduction Ratio= 1440/80 = 18 i.e. 1:18≈ 1:20

Belt Design

Belt Type A was selected based on the power to be transmitted (5 HP) according to Khurmi and Gupta, 2004 as shown in Table 1

Table 1. Dimensions of standard V-belts

Type of Belt	Power Range (kW)	Minimum Pitch (mm)	Top Width (mm)	Thickness (mm)
A	0.7-3.7	75	13	8
B	2-15	125	17	11
C	7.5-75	200	22	14
D	20-150	355	32	19
E	30-350	500	38	23

Source: Khurmi and Gupta (2004)

Belt Length

The length of the belts can be obtained using the equation below

$$L = \frac{\pi}{2}\left(D_1 + D_2\right) + 2x + \frac{\left(D_1 + D_2\right)^2}{4x} \quad (6)$$

Where L=Length of Belt,
D_1 is Diameter of Smaller Pulley, D_2 = Diameter of Larger Pulley, and x is Centre Distance of the Pulleys
Shaft Design
According to (Mischke, 2004), The diameter of the shaft can be obtained from the formula

$$D = \left[\frac{32N}{3\pi E \sum \theta} \left[\left[F_1 b_1 \left(b_1^2 - l^2 \right)^2 \right] + \left[F_2 b_2 \left(b_2^2 - l^2 \right)^2 \right] + \left(M_1 y_1 \left(3y_1^2 - l^2 \right)^2 \right) \right]^{\frac{1}{2}} \right]^{\frac{1}{4}} \quad (7)$$

For this design Where l is 640mm i.e. 0.64m
$\sum \theta$ is 0.0031 for steel from ASME
E is 207 $\times 10^9$ N/m^2
F_1 = 15.595 Kg = 155.95N
F_2 = 5.92 Kg = 59.2N
F_3 = 11,189N
b_1 = 455mm = 0.455m
b_2 = 185mm = 0.185m
y_1 = 185mm = 0.185m

$$D = \left[\frac{32 \times 1.5}{3 \times 3.142 \times 207 \times 10^9 \times 0.0031} \begin{bmatrix} \left(155.95 \times 0.455 \left(0.455^2 - 0.64^2\right)\right)^2 \\ + \left(59.2 \times 0.185 \left(0.185^2 - 0.64^2\right)\right)^2 \\ + \left(11189 \times 0.185 \times \left(3\left(0.185^2\right) - 0.64^2\right)^2\right) \end{bmatrix}^{\frac{1}{2}} \right]^{\frac{1}{4}}$$

$D = 0.0397m = 39.7mm \approx 40mm$
Note: The values of b and y in equation (7) were the locations of the points at which the forces acted upon the shaft with respect to the dye at the far end of the pelletizer.

Operation and Test Run

The screw type pelletizer operates based on the principle of extrusion achieved by forcing a large quantity of materials through smaller holes, in the process yielding shape of the orifice the material is forced through. The mixture of Kenaf and binding agent enters the pelletizer barrel through a square orifice directly from the plate mill, the mixture is then conveyed along the barrel towards the cone at the end of the barrel, and the mixture is then forced through the cone through the aid of the pointed end of the shaft embedded into the cone.

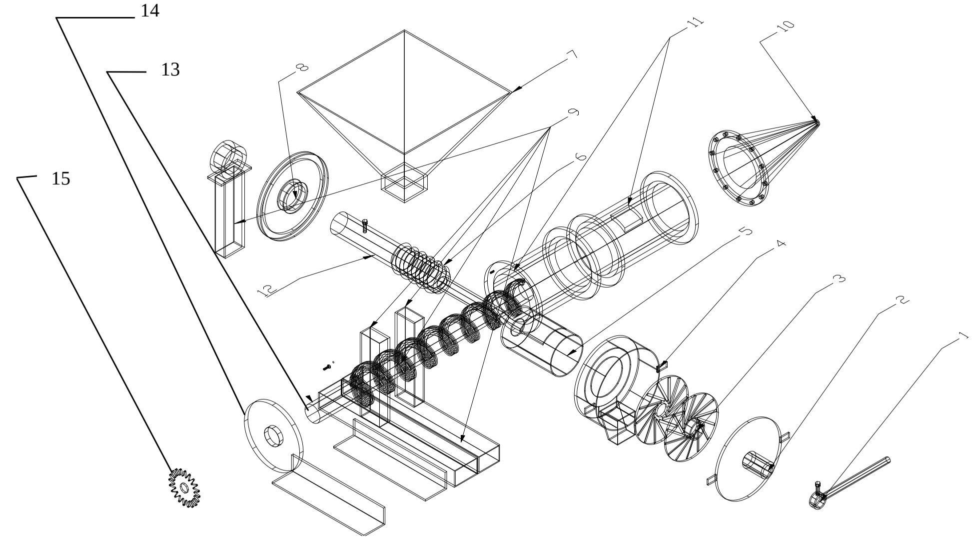

Fig. 2. Components of the Machine

1—Stopper /Lock screw for Grinder
2—Cover of Grinding Plates
3—Grinding Plates
4—Housing for the Grinding Plates
5—Shaft housing (Pipe) for the Grinder
6 &9 —Grinder Stand
7—Hopper
8—Pulley
10— Cone/Mould
11—Pelletizer Barrel
12—Grinder Shaft
13—Pelletizer Shaft
14—Back Cover of the Pelletizer
15—Sprocket

Plate 2: The Combined Grinding and Pelletizing Machine

Performance Evaluation

Testing of the machine is compulsory and an important step in the development of machineries, as it aids in determining efficiency of developed machines and as well as the best condition under which the machine can operate to yield maximum output, according to Nasir, 2005; testing is necessary for the following reasons: Testing the developed machinery helps to expose defect and area of possible improvement.

Testing developed machines helps to determine the performance of the machine and Testing also to assess the level of success of the development of the machine.

Procedure for Testing Using Binders

Eight Hundred grams (800g) samples each of ground Kenaf fibres of three different particle sizes D_1, D_2 and $D_{3,}$ 2.36*mm*, 1.18*mm* and 0.6*mm* respectively were mixed with 360g, 370g and 380*g* of Starch Cissus. The same procedure was repeated using 265*g*, 275*g* and 285*g* of Cissus gum and 1175*g*, 1230*g* and 1285*g* of animal feed.

Results and discussions

The machine was designed to powered by a 5 HP electric motor with the grinder running at a speed of 720*rpm* and the pelletizer at a speed of 72*rpm*, the performance of the machine was highly satisfactory, the machine reduces stress and time lost in manually moulding pellets and enhances handling of Kenaf fibre to be utilized in environmental remediation of oil spilled water bodies. The pelletizer was tested on the basis on the Pelleting Efficiency, Percentage Recovery and Throughput of the machine as obtained from the equations below:

$$\eta(\%) = \frac{W_P}{W_T} \times 100\%$$

$$R(\%) = \frac{W_A}{W_T} \times 100\%$$

$$T_C = \frac{W_T}{T}$$

Where:
η is the Pelletizing Efficiency
R is the Recovered Percentage
T_C is the throughput Capacity of the machine
W_P is the Total mass of Pellets Produced by the Machine
W_T is the Total Mass of Input (Kenaf and Binder)
W_A is the Total Mass of Output from the Machine and
T is the Time Taken for the Machine to Produce Pellets

The testing of the screw type pelletizer was carried out using three different particle sizes, three organic binders used at different quantities to determine the pelleting Efficiency, Percentage Recovery and Throughput Capacity of the machine as portrayed in Table 2 ana Figures 1a-1c and 2a-2c shows the surface response of pelleting efficiencies and throughput capacities to binder quantities and pellet diameter.

Table 2. Performance of the Kenaf Pelleting Machine at Three Different Particle Sizes Using Three Binders

Binder	Quantity of Binder (g)	Pelleting Efficiency (%)			Percentage Recovery (%)			Throughput Capacity (Kg/Hr)		
		D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
Cissus	265	82.22	84.62	87.23	86.29	87.98	90.07	32.77	34.11	35.49
	275	82.37	84.80	87.16	86.58	88.27	90.27	32.74	34.09	35.48
	285	82.47	85.03	87.58	86.87	88.77	91.11	32.72	34.07	35.45
Starch	360	79.14	80.63	82.09	85.00	87.20	89.02	33.88	33.83	34.77
	370	79.5	80.92	82.29	85.46	88.10	90.04	33.87	33.81	34.75
	380	79.84	81.08	82.45	86.18	89.12	90.61	33.86	33.79	34.73
Animal Feed	1175	89.87	91.81	93.26	90.23	92.16	93.56	36.84	37.06	37.88
	1230	89.95	91.88	93.45	90.39	92.36	93.82	36.83	37.04	37.87
	1285	90.02	91.93	93.54	90.53	92.56	94.03	36.82	37.02	37.86

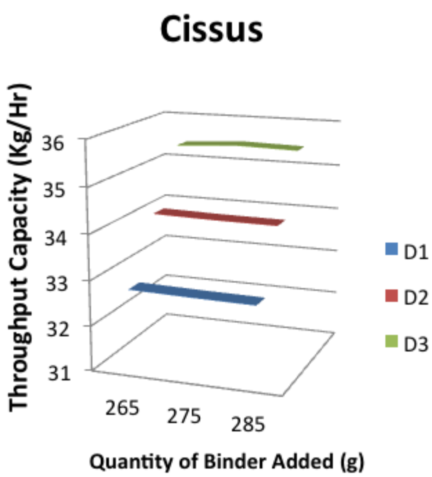

Fig. 1a. Surface Response of Throughput Capacity to Cissus Quantity and Pellets Diameter

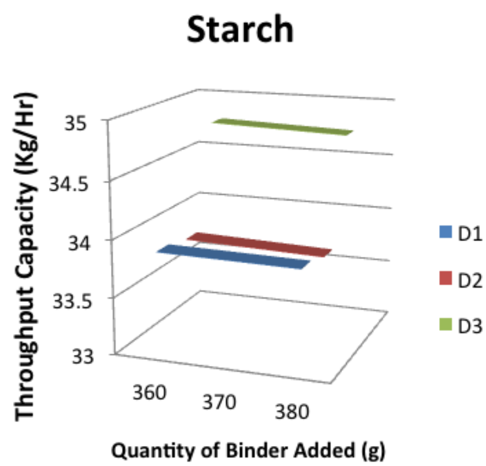

Fig. 1b. Surface Response of Throughput Capacity to Starch Quantity and Pellets Diameter

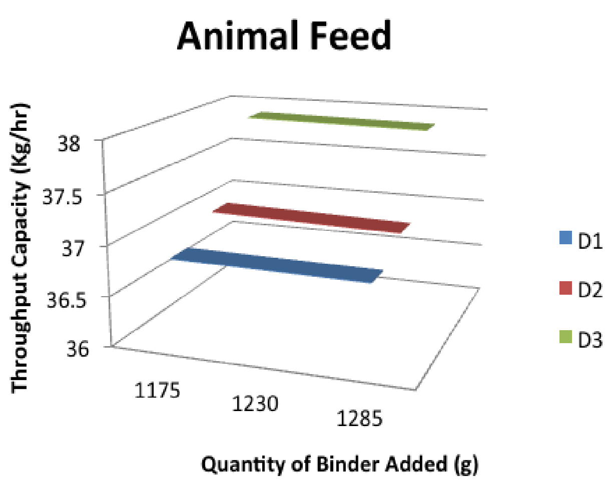

Fig. 1c. Surface Response of Throughput Capacity to Animal Feed Quantity and Pellets Diameter

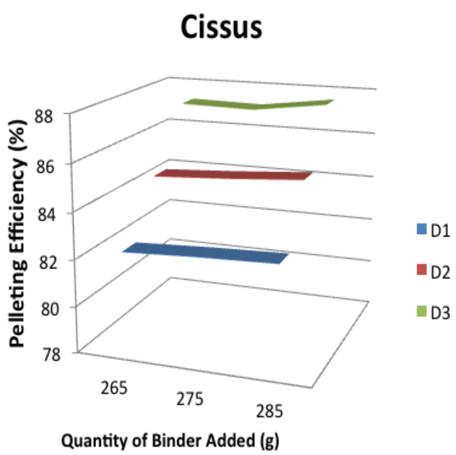

Fig. 2a. Surface Response of Pelleting Efficiency to Cissus Quantity and Pellets Diameter

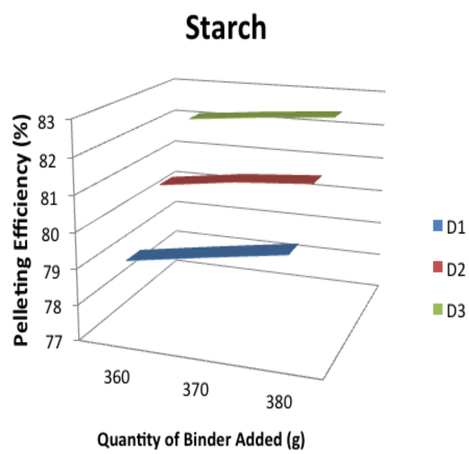

Fig. 2b. Surface Response of Pelleting Efficiency to Starch Quantity and Pellets Diameter

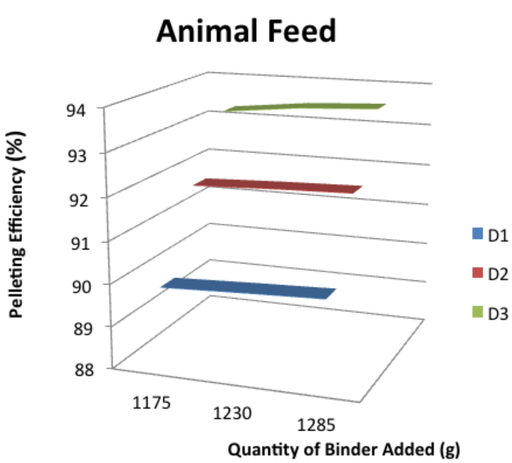

Fig. 2c. Surface Response of Pelleting Efficiency to Animal Feed Quantity and Pellets Diameter

Discussion

From the result of the tests, the Pelleting Efficiency of the machine was found to be within 82.22 % and 87.58 % when Cissus gum was used as binding agent, 79.14 % and 82.45 % when Starch was used as binding agent and 89.87 % and 93.54 % when Animal Feed was used as binder, this varied on the particle sizes of Kenaf used as well as the quantity of binder added. The percentage recovery of the machine had values within the range of 90.23 % and 94.03 % for Animal Feed while the utilization of Cissus gum yielded percentage recovery values between 86.29 % and 91.11 % and the machine had percentage recovery values between 85 % and 90.61% when starch was used as binder. However, the throughput capacity of the machine starch was used a binder fell within the range of 33.88*kg/hr* and 34.77*kg/hr* while Cissus gum produced pellets of throughput within 32.77*kg/hr* and 35.49*kg/hr* and the throughput capacity of the machine was between 36.84*kg/hr* and 37.88*kg/hr*. it is obvious that from the parameters above that the machine's performance is acceptable for a fibrous crop as Kenaf.

Conclusion

A combined Kenaf grinder and pelletizer was designed and constructed tested, the machine is to be powered by a 5 HP electric motor, the machine can be operated by an individual and can be used to make pellets to be used in environmental remediation of oil spilled water bodies. The machine was used to produce pellets at three different particle sizes using three different organic binders, the pelleting efficiency and percentage recovery increased as the quantity of binder added increased while the throughput capacity reduced as the amount of binder increased.

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