Design of a sawdust pelleting machine
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Abstract
This paper seeks to carry out the design of a pelleting machine with a capacity of 900kg per hour for the Company X. Apparently the boilers at the plant are using wood chips, a by-product from the milling operations as their source of fuel but off late the plant has been experiencing a serious fuel shortage. The fuel crisis emanated from low plant availability caused by old and dilapidated machinery. Major breakdowns that brings the plant to a halt for long hours are abrupt and rampant and during that time no wood chips are produced resulting in a fuel shortage. Following this fuel shortage the boiler operators have resorted to rationing the fuel input into the boiler as it has to run continuously regardless of whether the plant is moving or not. This rationing has resulted in poor boiler performance and low efficiency which has in turn affected the timber drying kilns. The boilers are producing poor quality steam which has had the effect of doubling the timber drying cycles. As a result of doubled timber drying cycles half of the timber produced is sold as wet off sawn at a relatively low price which is a loss to the company. The management and the engineering team in a bid to do away with this problem proposed the use of sawdust as additional boiler fuel. After a consideration of the type of boiler fire grates at the plant it was found that raw sawdust cannot be used as it has a tendency of choking the grates blowing out combustion so it has to be pelletized. With this problem at hand this project zeroed in at the design and development of a pelleting machine that will specifically meet the pellets need at the wattle company. Literature review was done on several types of pelleting machines’ operating mechanisms and from this literature three possible concepts were generated. These concepts were evaluated and the best was chosen and developed into a finished design ready for fabrication with all working drawings available for each component. The machine was designed with a constraint budget of USD $10 000 and it will provide a backup and additional boiler fuel to the already being used wood chips.
Keywords
Pelleting, Saw dust, Pelleting machine, Old equipment, Boiler fuel shortage, Maintenance.

1. Introduction
The machinery at the Company Y plant is now old, dilapidated and is operating mainly under corrective maintenance and as a result major breakdowns which halt the plant are abrupt. These downtimes cause serious boiler fuel shortage as the boilers use wood chips which are part of the waste material produced from the milling operations. There is also a scheduled maintenance plan that operates during the weekend and during the effect of this maintenance only one shifts run production instead of the normal two and at times there is no production at all. These factors significantly affect production and there is bound to be a shortage of boiler fuel since the boilers are run continuously regardless whether the plant is operating or not. To solve this problem there is need to convert waste sawdust into useful boiler fuel by pelletizing it since raw sawdust cannot be directly fed into the boiler. Raw sawdust tends to choke the fire grates causing electric motors to trip blowing out the combustion. This paper aims at designing a cheap wood pelletizing machine for making sawdust pellets which are a suitable fuel for the two Babcock and Wilcox boilers at the plant. A wood pelletizing machine grinds wood and sawdust into small fragments moisturizes and compresses it under very high pressure and temperature. The material is then forced through dies of the desired dimensions resulting in pellets.

1.1 Background
The wretched operating conditions of the main milling plant have resulted in the company failing to meet the market’s timber demand. In an effort to rectify this problem the management has contracted small mobile bush millers to help the company meet its targets. These millers operate from the company’s estates and they incinerate their waste material there bringing only the end product structural timber to the main mill for drying and warehousing purposes. Timber from both the mobile millers and the main mill is dried in Bollman kilns using super-heated steam from the boilers. Timber drying cycles have doubled following the low boiler efficiency caused by the fuel shortage. At the present moment the kilns are only capable of drying half the amount of the timber produced and the other half is sold as wet off sawn timber at a lower price. Fuel shortage has adversely affected the boiler efficiency and currently they are operating at a pressure lying between 50 and 120 bars instead of the optimum 150bars.

During the weekdays production is run continuously by two shifts only stopping at break, lunch and hand over take over times. The sawmilling and timber processing operations at the plant produce a significant amount of waste material up to a maximum of 14 tonnes per day. At the present moment the incinerator is malfunctioning resulting in mountains of sawdust being disposed all over the plant. The main objective of this research are to design a cheap...
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木屑压块机不超过US$10,000，设计一个压块机的容量为900kg/h，并设计一个产生直径为4mm和32mm长度的木屑压块机。

2. Literature review
木屑是可燃的能源载体，它们被用作燃料（Justina, 2013）。木屑是已经在世界范围内被广泛使用，随着主要燃料价格的上涨和全球气候变化的突然加剧。木屑的使用在制造业和加工行业中也变得越来越流行。由于其木材业务，公司不想落后于这一趋势，因为他们正在朝着这一目标努力，以解决锅炉燃料问题。有两台压块机，一台是平头压块机，另一台是圆头压块机。首先设计的是平头压块机，然后基于前者的运行原理改进了后者。平头压块机用于小型到中型规模的压块生产，而圆头压块机用于中型到大型规模的压块生产。

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Net Calorific Value (CV) by mass</th>
<th>Net Calorific Value (CV) by mass</th>
<th>Bulk density kg/m³</th>
<th>Energy density by volume kJ/m³</th>
<th>Energy density by volume kJ/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood chips</td>
<td>12.5</td>
<td>3.1</td>
<td>250</td>
<td>250</td>
<td>3,100</td>
</tr>
<tr>
<td>Saw dust (air-dry): 20% MC</td>
<td>14.7</td>
<td>4.1</td>
<td>350-500</td>
<td>5,200-7,400</td>
<td>1,400-2,000</td>
</tr>
<tr>
<td>Wood pellets</td>
<td>19</td>
<td>5.2</td>
<td>400-600</td>
<td>7,600-11,400</td>
<td>2,100-3,200</td>
</tr>
<tr>
<td>Miscanthus (bale - 25% MC)</td>
<td>13</td>
<td>3.6</td>
<td>140-180</td>
<td>1,800-2,300</td>
<td>300-450</td>
</tr>
<tr>
<td>House coal</td>
<td>27-31</td>
<td>7.6-9</td>
<td>850</td>
<td>23,000-26,000</td>
<td>6,400-7,300</td>
</tr>
<tr>
<td>Anthracite</td>
<td>30</td>
<td>9.2</td>
<td>1,100</td>
<td>35,300</td>
<td>10,100</td>
</tr>
<tr>
<td>Heating oil</td>
<td>42.5</td>
<td>11.8</td>
<td>845</td>
<td>35,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Natural gas (NTP)</td>
<td>39.1</td>
<td>10.6</td>
<td>0.0</td>
<td>35.2</td>
<td>9.0</td>
</tr>
</tbody>
</table>

3. Methodology

3.1 Case study

2015年6月22日，环境管理署（EMA）访问了该公司，并对空气污染处以US$2000的罚款。木屑被转化成压块，用于发电。木屑压块机的使用使得公司在能源使用上更加环保。
fuel use comes in as a value added waste disposal method dealing effectively with environmental management system requirements. It is also in line with the much recommended and talked about cleaner production.

![Figure 2 Incinerator at the Pine Company.](image)

The abundance of wood and sawdust resources at the plant implies that the company will produce more pellets than what is consumed at the plant meaning the excess pellets can be packaged and sold thus creating income for the company. Pellets due to their low ash content and high calorific value will have a great market base.

![Figure 3 Sample of pellets ready for the market](image)

Pelletizing sawdust makes it suitable for the boiler design that is currently on the ground. The boilers make use of fire grates below as their burning surface. Raw saw dust cannot be directly fed into the boiler because it tends to block the fire grates blowing out combustion.

![Figure 4 Fire grate of boilers at Nyanga pine](image)

### 4. Results and discussion

#### 4.1 Design

The boiler at the company uses wood chips as its fuel with an average consumption of 1,440 kg per hour. Using the information from figure 6.1, daily boiler consumption is calculated as:

\[
\text{Daily Consumption} \left( \frac{1440 \times 3.5\text{CV of wood chips per kg}}{24} \right) = 120,960\text{ kWh}
\]

Weekly consumption \( (120,960 \times 7) \)

\( = 846,720 \text{ kWh} \)
4.1 Theoretical Fuel produced from the sawmilling operations
The Pine plant on average processes 400 cubic meters of raw logs per day. All things being equal, the plant having its highest availability enough boiler fuel is produced from the milling operations. After timber processing 56% of the volume input goes to waste in form of sawdust and woodchips which contribute 14% and 42% respectively (USFS, 1987). Fuel supply \((400 \times 0.42 \times 870 CV \, \text{of wood chips per m}^2)\) = 140 279 kWh
Weekly fuel supply \((140 279 \times 7)\) = 981 955 kWh

4.1.1 Actual fuel produced
At the present moment the Nyanga pine plant is operating at a low plant availability of 75% as a result shortage of wood chips for boiler consumption is inevitable. Weekly Fuel available (981 955 x 0.75) = 767 340 kWh

4.1.2 Weekly Fuel shortage
Theoretical – actual fuel produced (981 955 - 767 340) = 214 615 kWh
From the above calculations the pelleting machine should have a capacity to produce pellets which will supply energy equivalent to 214 615 kWh.

4.2 Machine capacity
The quantity of pellets required to produce 214 615 kWh is calculated as follows using information from figure 4.

Volume of pellets \(\frac{\text{energy}}{\text{calorific value}}\) = \(\frac{214 615}{3 \times 10^5}\) = 69.2 m³
Mass of pellets \(\rho \times \text{volume}\) \((650 \times 69.2)\) = 45 140 tonnes

Daily pellet production (5 working days a week) \(\frac{45 140}{5}\) = 9 028 tonnes
Hourly production (10 working hours a day) \(\frac{9 028}{10}\) = 902 kg

From the above calculations the pellet machine should have a capacity of 900 kg per hour working 10 hours a day, 5 days a week.

4.3 Area of the roller causing shear of the material \(A_R\)
Pellet specifications: diameter 8 mm; length 32 mm
Volume of a single pellet \(\pi r^2 H (\pi \times 0.004^2 \times 0.032)\) = 1.6 \(\times 10^{-5}\) m³
Density of a standard pellet 650 kg/m³ (wiley, 2014)
Mass of a single pellet \((1.6 \times 10^{-5} \times 650)\) = 0.0104 kg
Number of pellets per hour \(\frac{500}{0.0104}\) = 86 538 pellets/hour
Pellets per 10 seconds (extrusion speed) \(\frac{86 538}{360}\) = 237.6 pellets
Die holes area \(\pi r^2 (\pi \times 0.004^2)\) = 0.000 050 m²
Area for 480 holes \((0.000 050 \times 238)\) = 0.012 m²
The area of the shear roller causing shear of the material \(A_R\) is equal to twice the total area of the die holes which is 0.024 m² (IJHIE, 2013).
4.4 shear stress acting at the roller-die contact point

Shear stress \( \tau = \mu \times \gamma \)

Where \( \mu \) = viscosity of the feed material, \( Nm^{-2} \)

\( \gamma \) = shear rate of the feed material, \( s^{-1} = \frac{V_R}{H} \)

\( V_R \) = roller speed \( m^{-1} \) (KAHL, 2014) and \( H \) = depth of the gear teeth on the roller, 0.002m

\( \mu = 32 \text{ Nsm}^{-2} \) (blaze, 2010)

\( \tau \left( 2000 \times 32 \right) = 64000 \text{ Nm}^{-2} \)

The shear stress acting on the roller-die contact is 64000 Nm^{-2}

4.5 Force required for pelleting \( F_R \)

Force \( F_R = \tau \times A_R \left( 64000 \times 0.024 \right) = 1536 \text{ newtons} \)

Since there are four rollers, the force applied will be multiplied by four

\( \left( 1536 \times 4 \right) = 6144 \text{ newtons} \)

The total force needed for pelleting is 6144 N

4.6 Power required for pelleting \( P_P \)

\( P_P = F_R \times V_R : (6144 \times 2) = 24576 \text{ watts} \)

The power required by the pelletizer is 24576 watts so a 25 KW electric motor is selected.

4.6.1 Speed of electric motor

Motor speed is calculated using these parameters:

Roller velocity \( V_R = 4 \text{ ms}^{-1} \) Roller diameter \( D_R = 0.14m \) (KAHL, 2014)

\( N_R = \frac{V_R \times 60}{\pi \times D_R} = \frac{4 \times 60}{\pi \times 0.14} = 546 \text{ rpm} \)

Velocity Ratio \( V \cdot R = \frac{D_d}{D_R} \cdot \frac{N_R}{N_d} \)

Where \( D_d \) is the diameter of the flat die; \( N_d \) is the rotational speed of the die in r.p.m

Thus \( N_d \) is found this way:

\( \frac{0.5}{0.14} = \frac{346}{x} \), \( N_d = 153 \text{ r.p.m} \)

The die shaft receives power through a gear drive connection with a velocity ratio of 3.1 therefore the pinion speed is 153 \times 3 giving 459 rpm.

The speed reduction gear drive receives power from a v belt connection connected to the electric motor with a velocity ratio of 2.1. The speed of the electric motor pulley is found by 459 \times 2 giving 918rpm.

From this we take standard the electric motor speed of 960 rpm.

4.7 design of power transmission belts

Power to be transmitted by the belt to the bevel gear shaft is 25kW from belt dimensions (GUPTA, 2005) and groove angle for different belts (GUPTA, 2005). From the above tables the specifications for belt C are as follows:
Table 2: Specifications for the belt

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving pulley diameter</td>
<td>=200mm</td>
</tr>
<tr>
<td>driven pulley diameter</td>
<td>=400mm</td>
</tr>
<tr>
<td>Top width</td>
<td>=22mm</td>
</tr>
<tr>
<td>motor speed $N_1$</td>
<td>=960 rpm</td>
</tr>
<tr>
<td>Thickness</td>
<td>=14mm</td>
</tr>
<tr>
<td>coefficient of friction $\mu$</td>
<td>=0.2</td>
</tr>
<tr>
<td>Weight per meter length</td>
<td>=3.43N/m</td>
</tr>
<tr>
<td>maximum stress $\sigma$</td>
<td>=2.1 MPa</td>
</tr>
<tr>
<td>Groove angle 2$\beta$</td>
<td>=38 degrees</td>
</tr>
<tr>
<td>cross sectional area $a$</td>
<td>=230 mm$^2$</td>
</tr>
<tr>
<td>Distances between centers $x$</td>
<td>=1m</td>
</tr>
</tbody>
</table>

4.7.1 Calculating the number of belts required

Power = $(T_1, T_2) \times n \times V$

Where $n$ is the number of belts required; $V$ is the belt speed in m/s; $D_D$ is the diameter of the driven pulley.

Belt speed $v = \frac{\pi \times D_D \times N}{60} = \frac{\pi \times 0.4 \times 450}{60} = 10.05$ m/s$^{-1}$

$\sin \alpha = \frac{d_1 \times M}{d_2 \times \sigma} = \frac{200 = 2 \times 1000}{2 \times 1000} = 5.7^\circ$

Angle of contact on the small pulley $Q_1 = 180 - 2\alpha = 180 - 2 \times 5.7 = 168.5^\circ$

$168.5 \times \frac{\pi}{180} = 2.94$ rad/s

Angle of contact on big pulley $Q_2 = 180 + 2\alpha = 180 + 2 \times 5.7 = 191.4^\circ$

$191.4 \times \frac{\pi}{180} = 3.34$ rad/s

When pulleys have different angles of contact the design is for the pulley with a small $\mu Q$ which is the smaller pulley.

$\mu Q = \mu \times Q_1 \times cosec $ $\beta = 0.2 \times 2.94 \times cosec 19 = 1.8^\circ$

Centrifugal tension in the belt $T_C$

$T_C = \mu a^2 (0.3496 \times 10.05 \times 10.05) = 35.33N$

$T = T_1 + T_C$ Where

$T$ is the maximum belt tension

$T_1$ is the tension in the tight side

$T = \sigma \times a (7 \times 230) = 1610N$

$T_1 = T - T_C (1610 - 35.33) = 1575 N$

$2.3 \log \frac{T_1}{T_2} = \mu Q_2 (0.2 \times 3.34) = 0.668$

$\frac{T_1}{T_2} = 1.95$

$T_2 = 808 N$

Power = $(T_1, T_2) \times n \times V$

$25000 = (1575 - 808) \times 10.05 \times n \quad n = 3.04$

Thus 3 belts are required.
4.7.2 Length of each belt (L)

\[ L = \pi \times (R_1 + R_2) + 2 \times \left( \frac{R_5 - R_1}{x} \right)^2 = \pi \times (0.2 + 0.1) + 2 \times 1 + \frac{(0.2 - 0.1)^2}{1} = 2.95 \text{ m} \]

Table 3: Materials for various components.

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulleys</td>
<td>Cast iron to reduce weight</td>
</tr>
<tr>
<td>Belts</td>
<td>Rubber</td>
</tr>
<tr>
<td>Driven pulley shaft</td>
<td>Mild steel</td>
</tr>
</tbody>
</table>

4.8 Selection of pellet cutting knife

The cutting knife is located below the revolving flat die. It is a stationary knife which cuts the emerging strands of feed into pellets as they are discharged from the pelletizer.

The pellets cutting knife is made of 2 mm mild steel having length of 30 mm and sharpened at the edges. The vertical position of the pellet cutting knife from the die determines the length of the cut pellets. Pellet cutting knife variables:

- Blade speed – Pelletizer has a stationary blade.
- Blade angle – 90 degrees to direction of rotation of flat die.
- Blade sharpness – 0.05-0.1mm range. The sharper the blade the less the energy required for cutting.
- Blade Clearance – Blade clearance between cutting edge and die was set between 10mm - 15mm for convenience.
- Moisture Content – Cutting force increased slightly with major decrease in moisture content. Moisture content of 20-30% wet basis is well suited for cutting without high deformation tendencies.

4.9 Design of the flat die

The die is made of stainless steel because of its great wear resistant properties. The pelletizing chamber housing the die and rollers is a hollow cylinder originating below the hopper and terminating below the flat die. The diameter of the chamber is 515mm. The diameter of the die is taken to be 500mm to allow for free rotation in the chamber of 515 mm diameter. The die holes are of diameters of 4 mm and the arrangement considered to be a pressure vessel.

The thickness of the die was calculated using the equation below.

\[ t = k \cdot D_d \cdot \frac{P}{\sigma_y} \]

Where,

- \( t \) = thickness of the die (mm)
- \( k \) = coefficient of friction which depends on the material (stainless steel 0.2)
- \( D_d \) = diameter of the die, 500mm
- \( P \) = compressive pressure of feed through the die holes. It is assumed that the maximum possible pressure developed by the rotating rollers will not exceed 150MPa.
- \( \sigma_y \) = yield stress for stainless steel is 280MPa.
The inlet of die holes is countersunk into taper shape to let feed stock flow into die holes. The inlet angle is usually around 30 to 40 degrees on small holes dies.

The die is machined using the milling machine and its drilling tools. The work piece is machined with relief steps for easy movement of the pellets after compression. The die holes are made using the G-codes of canned cycles.

The inner diameter $d_1 = 32$ mm and the outer diameter $d_2 = 40$ mm. The thickness $t$, to inner diameter ratio is $t/d_1 = 2.28125$. A cylinder with $t/d_1$ less than 0.05 is generally considered to be a thin cylinder and this die having a greater ratio is a thin walled cylinder with radial stress $\sigma_r$ and hoop stress $\sigma_h$ at a diameter $d$ in the cylinder body calculated as:

$$\sigma_r = \left(\frac{d_2^2 - d_1^2}{d_1^3} - \frac{d_1^2}{d_1^3}\right) \times \frac{d_2}{d_1^3} \times P_1$$  \hspace{1cm} (1)

$$\sigma_h = \left(\frac{d_2^2 - d_1^2}{d_1^3} - \frac{d_1^2}{d_1^3}\right) \times \frac{d_2}{d_1^3} \times P_1$$  \hspace{1cm} (2)

The minimum stress occurs at the die bore which is $d_3$ and the internal pressure is equal to the extrusion pressure.

$$P_1 = \frac{\text{design extrusion force}}{\text{bore area}} = \frac{6144}{\pi \times \frac{22^2}{16}} = 30.6\text{N/mm}^2$$

$$\sigma_r = \left(\frac{30^2 - 22^2}{22^3} - \frac{22^2}{22^3}\right) \times 30.6$$

$$\sigma_h = \left(\frac{30^2 - 22^2}{22^3} - \frac{22^2}{22^3}\right) \times 30.6$$

From equation 1 and 2 the radial stress at the bore is $P_1 = 30.6\text{ N/mm}^2$ and the hoop stress at the bore is $\sigma_h = 139.4\text{N/mm}^2$. The axial stress in this case is taken to be zero.

4.9.1 Checking the die strength

To check the die strength the maximum octahedral shearing stress criterion of failure is used. The criterion is given as:

$$\sigma_{0.2} = \frac{1}{\sqrt{3}} \sqrt{\left[(\sigma_h - \sigma_r)^2 + (\sigma_r - \sigma_x)^2 + (\sigma_x - \sigma_h)^2\right]}$$
\[ \frac{1}{3} \sqrt{\left(139.4 - 30.6\right)^2 + 30.6 - 0)^2 + 0 - 139.4)^2} = \frac{2}{3} \gamma \]

Figure 6: Misses results

\[ Y = 89.7 \, \text{N/mm}^2 \] which is less than the yield stress of mild steel \( Y = 280 \, \text{N/mm}^2 \). Therefore the die design is okay.

4.10 Roller frame design

The rollers are held by a four armed frame. The frame is made of a circular section with four arms attached 90 degrees apart. Polar moment of inertia
\[
J = \frac{2\pi r^4}{R} \times 0.05 \times 0.005 = 3.92 \times 10^{-5} \, m^4
\]

Torque of circular section
\[
T_{circular} = \frac{\pi r^4}{8} \times \frac{8 \times 10^5 \times 0.005}{0.05} = 4390.4 \, \text{Nm}
\]

Torque of bars
\[
T_{bar} = \frac{\pi r^4 d^2}{16} \times \frac{\pi r^4 x 10^6 \times 0.005^2}{16} = 1374 \, \text{Nm}
\]

Total torque
\[
= T_{circular} + 4T_{bar} = 4390.4 + 4 \times 1374 = 9886.4 \, \text{Nm}
\]

The maximum stress that can be transmitted using a safety factor of 1.5 on steel having elastic limit in tension of 300 N/mm\(^2\) is calculated using Maximum shear strain energy criterion of failure:

\[
\sigma_Y = \frac{1}{2} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]
\]

\[
\frac{300 \times 10^6}{1.5} = \frac{1}{2} \left[ (\tau - 0)^2 + (0 - (-\tau))^2 + ((-\tau) - \tau)^2 \right]
\]

\[
200 \times 10^{12} = 3\tau^2
\]

\[
\tau = 66.67 \, \text{N/mm}^2
\]

This maximum stress is more than the allowable design stress of 56 N/mm\(^2\) which means the design is safe.
4.11 Design of the hopper

The hopper is a truncated cone of gravity-flow type. The slant height is such that the content of the hopper empties unaided into the pelletizing chamber. For dough like materials of moisture content higher than 20%, the hopper slant angle is preferably between 60-70 degrees.

A hopper in form of a rectangular based pyramid frustum made of mild steel is considered. These dimensions are used in the design:

- Top face of the hopper: 1000mm x 1000mm
- Bottom face of the hopper: 300mm x 300mm
- Height: 750mm

The development of the hopper is such that the measurements are marked out and cut from a mild steel sheet as below and welded together.

![Figure 7 Development of hopper](image)

The flat die pelleting concept was chosen as the best solution and was further developed by doing all the necessary design calculations taking into consideration the safety factor whose value differed from component to component. Solid works Von Misses stress analysis was done for the main moving component of the mill which is the roller die section. Various methods of analysing failure criterion of all the other designed components was done to ensure the safety of the design and also to avoid over designing. Solid works was used in developing the 3D diagrams together with the working drawings.

![Figure 8.2 The full pelleting machine](image)

Above is the full design of the machine with two electric motors, one powering the worm screw and the other one powering the pelleting chamber. The feed comes in through the hopper where it is conveyed forward by the worm screw. The worm screw is situated inside the conditioning chamber where mixing into uniform malt is achieved.
Friction between the sawdust particles in the conditioning chamber produces heat which then starts to activate lignin, a natural binder found in sawdust. By the time the feed reaches the pelleting chamber it is well mixed which makes the pelleting process whole lot easier. The grinding of the rollers against the flat die generates heat which further activates lignin which holds the pellets in a compact form thus reducing fines.

The rollers are coupled to a roller frame with four arms and the frame itself is coupled to the rotating shaft. As the shaft rotates the rollers rotate in the same direction pressing and compacting the feed into the die holes thereby producing pellets. The rollers and the die are considered to be circular frictional plates. The die is considered to be a plain circular plate whilst the rollers are toothed circular plates. Rollers rotate inside scrapers whose job is to scrap off extra feed sticking on the rollers. If the feed is not scrapped it causes slipping on the roller-die contact.

The pelleting chamber is powered by a 25kW electric motor mounted on base of the machine. From the electric motor transmission is through V belts with a velocity ratio of 2:1 to the bevel gear connection. The bevel gears are meeting at a right angle and the power is transmitted with a velocity ratio of 3:1. The pinion shaft then transmits

5. Recommendations and conclusion
The environmental management agency should discourage the public and all timber processing industries from open burning of their waste. The waste from the production line should be converted into pellets which is a value addition process very much in line with the cleaner production ideology.
5.1 Policies
Apart from industrial boilers pellets can be used for domestic purpose and this will help reduce pressure on the much scarce electricity in our country. Since pellets are produced from trees they are considered renewable. As long as trees are replanted will never run out of sawdust pellets. Pellets also come in as a better alternative to raw wood because it burns with less ash and pollutants at the same liberating high amount of energy. The general public should be encouraged to use pellets as they have numerous advantages and this will help reduce strain on our limited non-renewable resources.

5.2 Re-designing
The design idea of the pellet machine can be re-structured to allow for further improvement of the system. The concept will be used to develop bigger and more robust machines that can be used for large scale production.

5.3 Conclusion
The pelleting machine has been designed with a production capacity of 900kg per hour. This project if resized to a larger scale can provide job opportunities to the unemployed graduates, and small-scale entrepreneurs can be empowered by the government by making pellets from sawmill wastes which is in line with the much emphasized cleaner production. This will reduce unemployment rate in Zimbabwe and dependence on petroleum products and nonrenewable coal for heating and cooking. It will also utilize waste generated by the sawmill industries thereby reducing open air burning and attendant environmental pollution.

References
5. Blaze, 2010. basic wood properties. s.l.:s.n.
11. IJEIR, 2013. s.l.:s.n.

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Biography

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