Performance Evaluation of Pellets Forming Unit in Local Feed Pelleting Machine
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ABSTRACT
This study was carried out to manufacture and evaluate a small local feed pelleting machine. The experimental studies were confined to determine the effect of: die speed (85, 95, 115, 160 &190 r.p.m.), die holes' diameter (3, 4 &5mm), moisture content of feed mixture (25, 28 & 31%), adhesive material (without any, molasses & gelatin) and different sources of power: (220V., AC, on grid system - Diesel generator - 1, 5 and 8 hours PV system). On some parameters of the study such as: productivity, pelleting efficiency, pellets durability, specific consumption energy and production cost. The experimental results showed that the highest value of pelleting machine productivity was 40.220 kg/h at die speed 190 rpm., 5mm die holes' diameter and 28% moisture content of feed mixture with gelatin as adhesive material in feed formula. At the same conditions, the pelleting efficiency was 98.082 %, pellets durability was 97.420%, specific consumption energy was 15.08 kW.h/ton and production cost was 39 LE/ton.

INTRODUCTION
It is desirable to have the pelleting machine which can produce efficiently the pelleted roughage which has the hardness appropriate for feeding purpose, but not easily be collapsed during the handling. Susawa (1978), Fouada et al. (2015) mentioned that protein shortage in Egypt results from high prices of protein production lines especially those imported from abroad. Manufacturing local pelleting machines will serve to solve the problem and reduce the production cost in comparison to imported machines. Kalyaan and Morey (2009) concluded that feed moisture content, biomass constituents, feed particle size, feed conditioning temperature, added binders and densification equipment variables as process parameters all affect feed durability. Kaddour and Elmetwalli (2015) concluded that increasing roller speed from 155 to 215 rpm with 10mm teeth width increased pellet mill production rate from 370.3 to 383.9 kg/h. Increasing roller speed over 215 rpm decreased the production rate. Highest pelleting efficiency of 98.6 was recorded at 230 rpm rollers speed. At all tested feeding rate, pellets durability increased with increasing roller speed . David (2003) mentioned that understanding the terminology used to describe dies is important when choosing die specifications, different feed and ingredients require specific amounts of time in the die hole-die retention time to be bind together to form a pellet. Larger die working areas provide more retention time to form pellets, reduce power consumption per ton of feed pelleted and improve production efficiencies. Abdel wahab et al. (2011) Observed that the highest production rate of 151.8 kg/h at real diameter of 4mm increased to 187.2 kg/h at real hole diameter of 5mm. Tabil and Sokhansanj (1996) mentioned that the durability of samples was generally better using the smaller die (higher (L/d ratio). Greer and Fairchild (1999) found that the moisture in feed mash affects pellets quality and production rates. Moisture in feed mash comes from two sources: bound moisture present in the feed ingredients and added moisture from water and steam addition. The moisture of cold feed entering the conditioner limits the amount of steam that can be added to the mash during conditioning. Tumuluru et al. (2011) found that increasing the moisture content of ingredient blends from 15 to 25% (w.b.) resulted in a 28.2% increase in durability. Tumuluru (2013) found that pellet moisture content decreased with increase in preheating temperature to about 110c and decreasing the feedstock moisture content to about 28% (w.b.). Tumuluru (2015) indicated that higher feed stock moisture content of 38% (w.b.) and a lower die speed of 2400 rpm. increased the specific energy consumption, whereas lower to medium preheating temperature (30-70c), medium feedstock moisture content of 33% (w.b.), and a higher die speed of 3600 rpm. minimized the specific energy consumption to<100 kWh/ton.

The aim of this study is to manufacture and evaluate a small local pelleting machine for animal feed, operated by different power sources. Farmer and small breeder can obtain this machine, because of its small size and it works by very low energy by comparing with imported machines of animal feed manufacturing. It can be manufactured in modest workshops, and can be manufactured in large quantities to cover the local needs.

MATERIALS AND METHODS
The main parts of the pellets forming unit in the animal feed pelleting machine:
The pellets forming unit in the pelleting machine consists of conical feed hopper, pellets forming unit (two pressing rollers and flat die), the main shaft, reduction unit (bevel gear, 1: 2.75 and pulleys 1:4), frame and axial wheels, as shown in Figures (1, a, b and c). The machine was driven by electric motor (one phase) of 0.75 kW, at 1440 r.p.m. through AC. 220 V. On grid or diesel generator of 2.5 kW, or electricity generated from photovoltaic panels of 1.2 kW.

Figure 1. A schematic diagram of the pelleting machine.
A. Pellets Forming Unit in Pelleting Machine

Table 1. Die hole-geometry:

<table>
<thead>
<tr>
<th>Die Thickness, mm</th>
<th>Die Diameter, mm</th>
<th>d</th>
<th>mm</th>
<th>L</th>
<th>mm</th>
<th>D</th>
<th>mm</th>
<th>No. of holes</th>
<th>Working area, cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>120</td>
<td>3</td>
<td>15</td>
<td>5.00</td>
<td>7</td>
<td>3</td>
<td>225</td>
<td>15.90</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>3</td>
<td>15</td>
<td>3.75</td>
<td>8</td>
<td>3</td>
<td>176</td>
<td>22.12</td>
<td></td>
</tr>
</tbody>
</table>

\( d = \) die hole diameter, \( L = \) land length, \( l = \) cone height and \( D = \) entry diameter.

5-Specific consumption energy, kW.h/kg: Multimeter was used for measuring current strength and potential difference, respectively before and during experiments. Readings of ampere (I) and volt (V) were taken before and during each treatment.

\[ \text{Consumed power, } P = \left( I \times V \times \cos \theta \right) /1000, \text{ kW} \quad \text{----(5)} \]

Where:
- \( I \) : Line current strength, Amperes.
- \( V \) : Potential difference, Volts.
- \( \cos \theta \) : Power factor, equal 0.76.

Specific consumption energy (kW.h/kg) = (consumed power (kW)) / (machine productivity (kg/h)) – (6)

6-Costs:

Fixed costs:
- Depreciation (Dep.): Declining balance method employed in calculating depreciation (Barger et al., 1979). The relationships are as follows:

\[ D = V_n - V_{n+1} \]

\[ V_n = C \left( 1 - R/L \right)^n, \quad V_{n+1} = C \left( 1 - R/L \right)^{n+1} \quad \text{----(7) \quad \text{----(8)}} \]

Where:
- \( D \) = amount of depreciation charged for year \( n + 1 \)
- \( C \) = original cost.
- \( R \) = the ratio of depreciation rate for used machines. It will be between 1 and 2 normally.
- \( L \) = service life.
- \( N \) = number representing age of machine in years at beginning of year.
- \( V \) = remaining value at any time (R.V.).

- Interest on investment, housing, taxes and insurance, (IHTI): It was estimated 13.8 % of the remaining value (Barger et al., 1979).

Operation costs (Variable costs):
- Repairs and maintenance (R and M): Repair costs are very high in developing countries and contribute significantly to the total cost. It was estimated 50% of the initial value, spread over the life of the machine, has been taken (Kaul and Egbo, 1985).
- Lubrication costs for a machine are equal to 10% of fuel cost (Barger et al., 1979).
- Fuel consumption, LE/h.
- Labor cost: The operator salary about 10 LE/h.

Total cost per hour (LE/hour) = Fixed cost (LE/year) + Operating costs (LE/year) – (9)

Production cost (LE/kg) = \( \frac{\text{Total cost per hour} \times \text{Productivity}}{1000} \) \quad \text{----(10)}

RESULTS AND DISCUSSION

1. Effect of die speed, die holes’ diameter, moisture content and adhesive materials on Productivity:

The results in fig. (2) showed the effect of die speed on pelleting machine productivity at different moisture contents of feed mixture using gelatin as adhesive material and die holes diameter 3mm. The results showed that as general trend, as die speed increases from 85 to 190 r.p.m., pelleting machine productivity increases for all die holes’ diameters, all moisture contents and with or without adhesive materials in feed formula. Pelleting machine productivity increases from 26.72, 30.128, 33.008, 36.614 to 40.22 kg/h and pelleting efficiency increases
from 97.584 %, 97.708 %, 97.833 %, 97.957 % to 98.082 % as die speed increases from 85, 95, 115, 160 to 190 rpm., respectively (at die holes’ diameter 5mm, using gelatin as adhesive material and 28% moisture content). Machine productivity increases from 32.66, 37.58 to 40.22 kg/h and pelleting efficiency decreases from 98.393 %, 98.269 % to 98.082 % by increasing die holes’ diameter from 3, 4 to 5mm, respectively (at 190 rpm die speed, 28% moisture content and using gelatin as adhesive material). At die speed 190 rpm pelleting machine productivity increases from 40.078 to 40.22 kg/h. Also, pelleting efficiency increases from 97.217 % to 98.082 % by increasing moisture content from 25% to 28% then machine productivity and pelleting efficiency decreases to 36.372 kg/h and to 97.530 % at 31% moisture content for die holes’ diameter 5mm and using gelatin as adhesive material. For 28% moisture content, die holes’ diameter 4mm and die speed 190 rpm, pelleting machine productivity increases from 24.26, 31.1 to 37.58 kg/h. Also pelleting efficiency increases from 97.833 %, 98.020 % to 98.269 %, respectively (using no adhesive material, using molasses & gelatin as adhesive materials respectively). The highest value of pelleting machine productivity was 40.22 kg/h at die speed 190 rpm., 5mm die holes’ diameter and 28% moisture content of feed mixture with gelatin as adhesive material in feed formula.

Fig. 2. Effect of die speed on pelleting machine productivity at different moisture contents of feed mixture using gelatin as adhesive material and die holes’ diameter 3mm.

2. Effect of die speed, die holes’ diameter, moisture content and adhesive materials on pellets durability:

The results in fig. (3) showed the effect of die speed on pellets durability at different moisture contents of feed mixture using gelatin as adhesive material at die holes’ diameter 3mm. As general trend, pellets durability increases by increasing die speed & increasing feed moisture content. It also, decreases by increasing die holes’ diameter. The pellets durability increases by using adhesive material in feed formula compared to feed formula without adhesive material. Also, the pellets durability of using gelatin as adhesive material in feed formula is higher than using molasses. At die holes’ diameter 5mm, using gelatin as adhesive material and 28% moisture content, the pellets durability increases from 90.2%, 91.52 %, 94.78 %, 96.1 % to 97.42 % as die speed increase from 85, 95, 115, 160 to 190 rpm. respectively. As die holes’ diameters increase from 3 to 5mm, the pellets durability decreases from 99.480 %, 98.480 % to 97.420 % by increasing die holes’ diameter from 3, 4 to 5mm respectively (at 190 rpm die speed, 28% moisture content and using gelatin as adhesive material). At die speed 190 rpm the pellets durability increases from 96.98 %, 97.42 % to 97.86 % by increasing moisture content from 25 %, 28 % to 31 % for die holes’ diameter 5mm and using gelatin as adhesive material. For 28% moisture content, die holes’ diameter 4mm and die speed 190 rpm, the pellets durability increases from 97.48 %, 97.88 % to 98.48 % respectively (using no adhesive material, using molasses & gelatin as adhesive materials respectively). The highest value of pellets durability was 99.92 % at die speed 190 rpm., 3mm die holes’ diameter and 31% moisture content of feed mixture with gelatin as adhesive material in feed formula.

Fig. 3. Effect of die speed on pellets durability at different moisture contents of feed mixture using gelatin as adhesive material at die holes’ diameter 3mm.
3. Effect of die speed, die holes’ diameter, moisture content, adhesive materials on specific consumption energy:

The results in fig. (4) showed the effect of die speed on specific consumption energy at different moisture contents of feed mixture using gelatin as adhesive material and die holes’ diameter 3mm. As general trend, specific consumption energy decreases by increasing die speed & increasing die holes’ diameter. It also, increases by increasing moisture content of feed mixture. The specific consumption energy decreases by using adhesive material in feed formula compared to feed formula without adhesive material. Also, the specific consumption energy of using gelatin as adhesive material in feed formula is lower than using molasses. At die holes’ diameter 5mm, using gelatin as adhesive material and 28% moisture content, the specific consumption energy decreases from 16.26, 15.85, 15.77, 15.39 to 15.08 kW.h/ton as die speed increase from 85, 95, 115, 160 to 190 rpm. Respectively. As die holes’ diameters increase from 3 to 5mm, the specific consumption energy decreases from 17.03, 15.45 to 15.08 kW.h/ton by increasing die holes’ diameter from 3, 4 to 5mm respectively (at 190 rpm die speed, 28% moisture content and using gelatin as adhesive material). At die speed 190 rpm the specific consumption energy increases from 14.78, 15.08 to 17.07 kW.h/ton by increasing added moisture content from 25 %, 28% to 31 % for die holes’ diameter 5mm and using gelatin as adhesive material. For 28% added moisture content, die holes’ diameter 4mm and die speed 190 rpm, the specific consumption energy decreases from 28.66, 20.75 to 15.45 kW.h/ton respectively (using no adhesive material, using molasses & gelatin as adhesive materials respectively). The lowest value of specific consumption energy was 15.08 kW.h/ton at die speed 190 rpm., 5mm die holes’ diameter and 28% moisture content of feed mixture with gelatin as adhesive material in feed formula.

![Fig. 4. Effect of die speed on specific consumption energy at different moisture contents of feed mixture using gelatin as adhesive material and die holes’ diameter 3mm.](image)

4. Cost analysis:

Figure 5 showed the production cost for pelleting machine using different die holes’ diameter (3,4&5mm) at die speed 190 rpm., 28% moisture content of feed mixture, with gelatin as adhesive material in feed formula and powered with different sources of power: (220V., AC, on grid system - Diesel generator - 1, 5 & 8 hours PV system). Production cost decreases by increasing die holes’ diameter due to increasing machine productivity. Production cost was 0.048, 0.042 & 0.039 LE/kg for die holes’ diameters 3, 4 &5 mm., respectively using 220V., AC, on grid as a source of power. Production cost was 0.087, 0.075 & 0.070 LE/kg for die holes’ diameters 3, 4 &5 mm., respectively using diesel generator as a source of power. Production cost was 0.061, 0.053 & 0.050LE/kg for die holes’ diameters 3, 4 &5 mm., respectively using 1-hours PV system as a source of power. Production cost was 0.083, 0.072 & 0.068 LE/kg for die holes’ diameters 3, 4 &5 mm., respectively using 5-hours PV system as a source of power. Production cost was 0.146, 0.127 & 0.118 LE/kg for die holes’ diameters 3, 4 &5 mm., respectively using 8-hours PV system as a source of power.

![Figure 5. Production cost at different sources of power and different die holes’ diameter 3,4&5mm at die speed 190 rpm., 28% moisture content of feed mixture and using gelatin as adhesive material in feed formula.](image)

CONCLUSION

The highest value of pelleting machine productivity was 40.220 kg/h at die speed 190 rpm., 5mm die holes’
diameter and 28% moisture content of feed mixture, with gelatin as adhesive material in feed formula and using 220V., AC, on grid as a source of power. At the same conditions, the pelleting efficiency was 98.082%, pellets durability was 97.420%, specific consumption energy was 15.08 kW.h/ton and production cost was 0.039 LE/kg.


REFERENCES


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