INFLUENCE OF GEOMETRIC DIMENSIONS OF EXTRUSION DIE HOLES ON MACHINE EFFICIENCY AND PELLETS QUALITY.

Kaddour, U.A.; *T. R. Owies; **M. K. Afify
**Assistant Professor Agric. Eng. Dept. Zagazig Univ

ABSTRACT

Both the geometrical dimensions of die and rations components are the most important parameters influencing the efficiency of extrusion machine and the quality of pellets.

Therefore, the main objective of the present study is to investigate the influence of geometrical dimensions of die such as; \[ \text{Length/Diameter (L/D ratio), hole entry diameter (D_{he}), die opening area (O_A_d), and thickness of die (T_{ho})} \] on both the efficiency of extrusion machine and the quality of produced pellets for two different kinds of ration (standard ration, and residual ration) to produce high quality of large animal feed pellets (g 12 mm).

The extrusion machine with different dies was evaluated for the two previously kinds of ration and taken into account the effective design parameters such as; [four levels of L/D ratio (1.42, 1.67, 1.92 and 2.17), hole entry diameter (16, 18 and 20 mm), percentage of die opening area (2.66, 5.33, and 7.99 %), and thickness of die (30 and 35 mm)], while the evaluation parameters were specified into two groups such as; a) machine evaluation parameters (productivity, energy requirements and total losses), b) pellets quality parameters (pellets durability, pellets bulk density, and pellets hardness).

The results indicated that the optimum conditions for producing a good quality of pellets from standard ration were 1.92 L/D ratio, 16 mm hole entry diameter, 5.33 % die opening area, and 30 mm thickness of die, when the evaluated parameters (machine productivity, energy requirements, total losses, pellets durability, pellets bulk density, and pellets hardness) were 0.399 t / h., 114.04 kW .h./ton, 5.21%, , 86.72%, , 1.190 g/ cm³, and 184.80 N, respectively.

On the other hand the optimum conditions for producing a good quality of pellets from residual ration were 1.67 L/D ratio, 20 mm hole entry diameter, 2.66 % die opening area, and 35 mm thickness of die, when the evaluated parameters (machine productivity, energy requirements, total losses, pellets durability, pellets bulk density, and pellets hardness) were 0.306 t / h., 153.10 kW .h./ton, 5.38%, , 90.35%, , 1.11 g/cm³, and 192.47 N, respectively.

The multi-regression analysis illustrated that the evaluated parameters could be thoroughly predicted as a function of the studied parameters as follows:

\[ Y_i = a + b X_1 + c X_2 + d X_3 + e X_4 \]

Where:
\[ Y_i = \text{machine productivity, energy requirements, total losses, pellets durability, pellets bulk density, and pellets hardness} \]
\[ X_i = \text{L/D ratio, hole entry diameter (D_{he}), percentage of die opening area (O_A_d), and thickness of die (T_{ho})}. \]
\[ a, b, c, d, e = \text{constants}. \]

INTRODUCTION

The factors that influence pellet quality can be divided into several categories. It is generally agreed that the formulation is, by far, the most important factor affecting pellet quality.
Reed (1980) mentioned that the work and pressure required for compaction or extrusion can be reduced by a factor of about two by preheating the raw material. Pellet quality is dependent upon several factors, such as: 1) feed formulation; 2) feed particle size; 3) mash moisture content; 4) conditioning; 5) die specifications; and 6) cooling.

Harper, (1981) said that the cooling die is the major component of the extruder setup and is responsible for the final shape and texture of extruded products such as meat analog. It is attached at the extruder outlet, and the cooling medium is circulated in the die jacket. A long cooling die is often used at the end of a twin-screw extruder to control the product temperature and to facilitate the texturization or fiber formation in the final product.

Noguchi,( 1989) said that its greater conveying angle and self-wiping feature make it possible to handle a wider range of ingredients compared to a single-screw extruder. It also eliminates or minimizes pressure and leakage flows by virtue of the direction of screw rotation, screw shape, screw configuration, and relative position of screw sections. These characteristics of the twin-screw extruder allow processing of high-moisture extrudates with improved texture and offer the possibility of taste modification.

Cheftel et al.(1992) reported that producing the textures of soy-beans protein requires the selection and control of extrusion variables such as extruder barrel temperature, feed rate, screw speed, die cooling, etc., at suitable levels. Essentially, the three steps for soy protein texturization are: (1) melting of the protein constituents inside the extruder as a result of high shear and temperature, (2) steady pumping of the food melts from the extruder into the die, and (3) development of a laminar flow in the cooling die to initiate fiber formation.

The cereal grain used (corn vs. wheat) and its percentage can have great influence. The inclusion of fats or oils (above 1%), regardless of the source, can dramatically reduce pellet quality. Fineness of grind can have a great deal of influence on pellet quality. In fact, the finer grinding, either pre- or post-grind, improving the pellet quality. Particle size affects both the extent of conditioning and the way in which particle bonding occurs in the pellet itself. In terms of pellet mill operations, the conditioning process has greater influence on pellet quality than does die specification. (Behnke 1994).

Pellet quality and durability are important factors if the benefits associated with pelleting are to be realized. Research shows that feed conversion of swine and poultry decreases as pellet fines increase. The improved feed-handling characteristics of pelleted feed also are diminished if pellets contain excessive fines(Schell and van Heugten, 1998).

McKinney et al. (2000) studied the effect of different temperatures on pellets hardness and they reported that the temperature is believed to affect quality but hardness results appear to be random. In another trial hardness had a negative correlation to durability .This is rare but it can occur. It appeared that molasses was added at variable levels during the pelleting run. Addition of molasses can make the pellet soft and gummy; it may even be possible to bend the pellet. Soft pellets can be very durable, making the hardness test an inappropriate method of measuring quality.
Samson and Duxbury (2000) found that the bulk density of switch-grass pellets ranged between 35-40 lbs/ft³. This value is similar to the density of pellets produced in the laboratory (38.5 lbs/ft³).

Jannasch et al. (2001) said that a reduction in screen size from (1/8) inch to (7/64) inch with approximately throughput 2 t/h for the fine grinding process appeared to produce a modest increase in pellet hardness. The binding quality of the feedstock and pellet durability could be improved by changes to the die configuration, steam treatment or natural additives. The energy requirement for pelleting switch-grass is estimated to be 0.416 GJ/ton. It is expected that energy efficiency could be increased substantially with the adoption of modern equipment in demonstration projects or by working with large-scale by typical die for alfalfa pellets has a (¼) inch diameter and 2 inch effective thickness.

Adapa et al. (2002) mentioned that understanding the terminology used to describe dies is important when choosing die specifications. Different feeds and ingredients require specific amounts of time in the die hole – die retention time – to be able to 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. They found that the bulk density of a dried straw is as low as 40 kg/m³, whereas the bulk density of pelletized grasses can reach as high as 1250 kg/m³.

David (2003) studied the terminology used to describe the characteristics and dimensions of die holes. He reported that the most important terms to understand when selecting a pellet die are: D = Hole Diameter: Typical hole diameters can range from 3/32nd to 3/4th inch. L = Effective Length: The effective length is the die thickness that actually performs work on the feed. L/d Ratio: The L/d ratio is the effective length divided by the hole diameter. High L/d ratios provide high pellet die resistance as feed moves through the hole and vise versa. Each material has an L/d ratio requirement to form the material into pellets. T = Total Thickness: Total thickness is the overall thickness of the die. Overall thickness provides the necessary die material to avoid die breakage. X = Counter bore Depth: Counter bore depth measures the "relief" provided in the die as the pellet exits from the die hole.

Lebaal et al (2005) mentioned that the defects of extrusion (like the weldlines, the fairly uniform exit velocity distribution throughout the extrusion and problems of stagnation zones) are influenced by the geometry of the die of extrusion as well as by the operating conditions such as temperature of regulation, flow rate and the Rheological parameters of melt.

Lee et al (2005) studied the heat transfer between the cooling die and product, and they found that the analysis of heat transfer is valuable for die geometrical design and product temperature at the die outlet, both are important for the texturization process and the control of meat analog quality during process scale-up. Based on the heat transfer analysis, equivalent heat transfer coefficients between the cooling die and product were estimated and were used to predict product temperatures. Predicted product temperatures were, generally within 6.8°C of the measured values depending on the size of the cooling die, the feed moisture content, and the cooling medium.
MATERIALS AND METHODS

Composition of the experimental rations.

Tow large animal experimental rations were used in this study; their compositions are given in Table (1). The ration particles fineness were average 3mm mixed with 22% of water, pelleted through extruder pelleting machine with hole die φ 12 mm.

Table (1): Composition of the experimental large animal rations*

<table>
<thead>
<tr>
<th>Composition</th>
<th>Standard ration</th>
<th>Residues ration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>41</td>
<td>22</td>
</tr>
<tr>
<td>Wheat</td>
<td>25.2</td>
<td>20</td>
</tr>
<tr>
<td>Soy bean meal</td>
<td>13</td>
<td>---</td>
</tr>
<tr>
<td>Flax meal</td>
<td>12</td>
<td>---</td>
</tr>
<tr>
<td>Cotton seed meal</td>
<td>---</td>
<td>36</td>
</tr>
<tr>
<td>Germa</td>
<td>---</td>
<td>9</td>
</tr>
<tr>
<td>Cube</td>
<td>---</td>
<td>10</td>
</tr>
<tr>
<td>Molasses</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>Limestone</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Salt</td>
<td>1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Pri- mix</td>
<td>0.3</td>
<td>---</td>
</tr>
</tbody>
</table>

* According to the obtained knowledge from Animal Production Research Institute.

The specification of the extruder pelleting machine

The tested extruder pelleting machine was fabricated in local workshop to produce different types of animal feed with different diameters of pellets ranged from 3 up to 12 mm equivalent to the die hole diameter, the construction feature of the extruder pelleting machine mainly consists of the following units Fig. (1):

1- Feeding unit.

Feeding unit was constructed from iron steel 37 and consists of feeding hopper with mixer blades used for mixing the rations. The feeding auger was horizontally leveled with 0.2 mm ground clearances with the case. It was fitted directly under mixer to push the ration inside the extruder with continuous flow.

2- Extrusion unit:-

Extrusion unit compress the feed diet through the extruder cylinder to the forming die, it includes the following parts:

a- Extruder cylinders:

The extruder cylinders consist of five cylinders made of hard steel used for covering compressing screw units and steam-lock parts. The first cylinder unit named feeding cylinder fixed with the base by six screw bolts (M12x1.5), it has a square hole 57x 57 mm connected under the feeding unit, their dimension (250 mm long, 104 mm diameter and 12mm thick). The dimensions of the next three units were (180 mm long, 104 mm internal diameter, and 12mm thick). Whereas The last cylinder unit named die house with dimension of (45 mm long, 104 mm diameter, and 12 mm thick). The internal surface of all the cylinders has incisions to impress the meal pass forward with screw direction.

340
Fig. (1): Schematic diagram of the extrusion machine and forming unit (die).

b- Main compressing shaft:  
The compressing shaft made from hard steel 52, has dimensions of (145.5 cm long and 60, 55, and 50 mm gradually diameters) with keyway 12 x
6 mm on the 50 mm diameter used to support the screws and the steam-lock to prevent slipping of the screws and occur a highly compression efficiency.

C- Compressing screw:-
There are five Compressing screws made from hard steel 52, each unit has a demission of (150 mm long, 95 mm diameter, and pitch of 35 mm)

3- Forming unit (Dies):-
The die is the most important part in the extruder machine which block the cylinder from the end. It was fixed in the die head using screw bolt (M8x1.2) and two guides to prevent the rotation during operation and keep the clearance with the screw shaft to be 3 mm. It was made from hard steel (100 and 94 mm for the two levels of the outside diameters, 30 and 35 mm thick). It has 2, 4 and 6 holes ($\phi$ 12 mm) with a different wider conical form in the entry side as shown in Fig.(2 and 3).

The opening area could be calculated according to the following equation:

$$OA_D = \frac{n \cdot a_{\text{hole}}}{A_{\text{total}}} \times 100$$

where:

- $OA_D$ = Die opening area, %
- $n$ = number of holes
- $a_{\text{hole}}$ = area of one hole, cm$^2$
- $A_{\text{total}}$ = area of the total die, cm$^2$

Fig. (2): Geometrical dimensions of the tested dies.

4- Cutter knife:
Cutter knife was made from steel 37 (100, and 25 mm for the outer and inner diameters with 10 mm thick), consists of 4 blades with a sharp edges used to cut the obtained pellets from the tested machine.

5- Power Unit:
The main power unit was an electric motor with 1450 rpm rotational speed at 50 hp rated power, with 43 A. It was used to operate the extrusion machine through reducer sprocket and chains.

Study parameters:
The performance of the tested dies of the pelleting machine such as; (machine productivity, energy requirements, and total losses) and the quality of the produced pellets such as; (pellets durability, pellets bulk density, and pellets hardness) were evaluated under the following parameters:

a) Parameters related to the machine (different Dies):
1-L/D ratio: The L/D ratio is the relation between the effective hole length and real hole diameter, four levels of L/D ratio were studied (1.42, 1.67, 1.92 and 2.17).
2-Hole entry diameter: three levels of hole entry diameter were studied (16, 18 and 20 mm.)
3-Percentage of opening area: Opining area % is the percentage between the total openings areas of holes to the die total area, three levels of opening areas were studied (2.66, 5.33 and 7.99 %).
4-Die thickness: two levels were studied (30 and 35 mm).

b) Parameters related to the rations:
1- Different rations: The above parameters were tested and evaluated with two different kinds of rations [standard ration, and residual rations], the compositions of investigated rations are tabulated in table (1).

![Diagram](image)

Figure (3): Schematic diagram for different types of the investigated dies.

The following relations were used:

1- Production rate: \[ \text{Production rate} (t/h) = \frac{W_p}{T} \times 3.6 \]

where: \( W_p \): pellets yield mass (kg.) \( T \): consumed time (sec.)
2-Energy requirement:

\[ \text{Energy requirement (kWh/ton)} = \frac{\text{Power (kW)}}{\text{production rate (ton/h)}} \]

3-Total losses: (un-pelleting ration)

Where: \( W_p \) = pellets yield mass (kg)
\( W_t \) = sample mass (kg)

4-Pellets durability:
The durability of pellets was determined according to ASAE standard (1992). Since pellets were sieved on the appropriate sieve to remove fines. A sample mass of about 500g placed in the tumbling box device for tumbling up to 10 min, the sample will be removed, sieved and the percent of whole pellets calculated as follows:

\[ \text{Durability (\%)} = \frac{W_a}{W_b} \times 100 \]

Where: \( W_a \) = pellets mass after treatment (g)
\( W_b \) = pellets mass before treatment (g)

5-Pellets bulk density:

\[ \text{Bulk Density (g/cm}^3\) = \frac{W_d}{V_d} \]

Where: \( W_d \) = pellets sample mass (g)
\( V_d \) = pellets sample volume (cm\(^3\)).

6-Pellets hardness:
Pellets hardness was measured by digital force gauge named (Shimpo) with an accuracy 0.1 N. The conical head were used as shown in Fig. (4).

RESULTS AND DISCUSSION

1-The Influence of geometric dimension of die holes on machine productivity:
The obtained results indicated that the production rate affected directly by the investigated parameters such as; (die entry diameter, die thickness, L/D ratio, and the percent of die opening area). The productivity was increased by increasing both the percent of die opening area, and die entry diameter, but it was decreased with increasing both L/D ratio, and die thickness.

Referring to the L/D ratio, increasing L/D ratio from 1.42 to 2.17 decreased the production rate from 6.33, to 6.12 % for the standard ration and from 15.15, to 11.11% for the residual ration at die thickness 30 mm. Whereas, increasing the die thickness from 30 to 35 mm, the percent of productivity decreased from 8.57 to 6.38% for the standard ration, and from
15.63 to 9.30% for the residues ration at percent of die opening area of 2.66, 5.33, and 7.99 respectively and die entry diameter of 18 mm.

Notify to the die entry diameter, increasing the die entry diameter from 16 to 18 mm increased the production rate up to (4.26, 2.13, 2.17 and 4.55%), and (4.63, 2.33, 4.88, and 2.56%) for both the standard ration, and the residues ration, respectively, at die thickness of 30 mm.

By increasing the die thickness up to 35 mm, the results illustrated that, the production rate increased from 2.17, 4.44, 2.27, and 2.33% for the standard ration, and from 2.38, 4.88, 2.50, and 2.63% for residues ration with the investigated L/D ratio 1.42, 1.67, 1.92, and 2.17, respectively, and percent of die opening area of 8.64% then beginning to decrease with increasing the die entry diameter from 18 to 20 mm as shown in Fig.(5).

Remaking to the percent of die opening area, it was indicated that increasing the production rate from 36.11, 37.19, 38.24, and 39.39% for the standard ration and to 36.35, 37.50, 43.33, and 42.86% for the residues ration at die entry diameter of 18 mm and die thickness of 30 mm, while increasing the die thickness up to 35 mm, the production rate increased to 34.29, 38.24, 36.36, and 37.5% for the standard ration, and to 34.24, 38.71, 41.38, and 44.44 for the residues ration under the condition up increasing the die opening area from 2.66 to 7.99% and L/D ratio of 1.42, 1.67, 1.92, and 2.17 respectively.

The reason for decreasing the production rate by increasing L/D ratio and or die thickness may be due to the increasing in effective hole (working thickness) and the material spending more time inside the die holes (increasing the retention time).

Also, increasing the production rate by increase the die hole entry diameter could be due to the easy flow of ration inside the working thickness.

In addition; the increase in production rate with increasing the opening area could be due to the increase of output area of die and decrease in press time. Therefore the increase in production rate in standard ration than residues ration could be due to the high in fat and protein which make the ration flow easily in die holes.

The obtained data from the multi-regression analysis between the machine productivity and the interaction between the studying parameters produced the following equations:
A) for standard ration:
\[ P = 0.402 - 0.003 \theta_0 + 0.024 O_{A0} + 0.0015 D_{wa} - 0.041 \frac{L}{D} \] \[ R^2 = 0.9889 \]
b) for residues ration:
\[ P = 0.389 - 0.003 \theta_0 + 0.022 O_{A0} + 0.0017 D_{wa} - 0.057 \frac{L}{D} \] \[ R^2 = 0.9846 \]
where:
- \(P\) = the machine productivity, l/h;
- \(\theta_0\) = die thickness, mm;
- \(O_{A0}\) = percentage of hole opening area, %;
- \(D_{wa}\) = hole entry diameter, mm;
- \(L/D\) = the ratio between hole length and hole diameter

2- The influence of geometric dimension of die holes on energy requirement:

The energy requirements corresponding with the production rate and factors affected with it, the energy requirement increased by increasing both the L/D ratio and die thickness, and decreased by increasing the die entry diameter, percent of die opening area, and for residues ration.
Fig. (5): Effect of L/D ratio, die entry diameter, Percentage of opening areas, and two rations component on extruder productivity.
The obtained data illustrated that, increasing L/D ratio from 1.42 to 2.17 increased the energy to 42.75, 42.18, and 41.15 % for the standard ration, and to 49.15, 49.22, and 46.24% for the residues ration at die thickness of 30 mm, also by increasing the die thickness to 35 mm, the energy increased by 42.88, 42.71, and 40.86% for the standard ration, and by 48.39, 44.24, and 45.96% for the residues ration at percentage of die opening area of 2.66, 5.33, and 7.99% respectively and die energy diameter of 18 mm.

Remarkably to the die entry diameter, increasing the die entry diameter from 16 to 18 mm the energy reduced by 4.77, 3.36, 3.29, and 5.18% for the standard ration and by 4.83, 4.55, 4.28, and 4.57% for the residues ration at die thickness of 30 mm.

By increasing the die thickness to 35 mm, the results showed reduction by 4.01, 4.58, 3.82, and 3.93% for the standard ration, and by 4.68, 5.01, 6.63, and 4.15% for the residues ration at L/D ratio of 1.42, 1.67, 1.92, and 2.17 respectively and percentage of die opening area of 8.44%, then started to increase with increasing the die entry diameter from 18 to 20 mm as shown in Fig.(6).

Relating, to the die opening area, it found that increasing the opening area of die from 2.66 to 7.99% reduced the energy by 30.23, 30.07, 30.41, and 31.01% for the standard ration, and by 30.60, 30.49, 31.46, and 31.95% for the residues ration at die thickness of 30 mm.

By increasing the die thickness to 35 mm, it noticed that the energy reduced by 30.25, 30.51, 30.10, and 31.24% for the standard ration, and by 31.32, 31.63, 33.61, and 32.44% for the residues rations under the condition of L/D ratio of 1.42, 1.67, 1.92, and 2.17 respectively.

The increase of energy requirement by increasing both L/D ratio and die thickness could be attributed to the increase in compression load on die and increase in power consumed with the decrease of production rate. While the decrease of energy requirement by increasing the die entry diameter and opening area could be due to the decrease of the load on die.

The increase in energy requirement in residues ration over the standard ration could be due to the component of residues ration which need more press and consumed power to flow through the die holes.

The obtained data from the multi-regression analysis between the energy requirements and the interaction between the studying parameters produced the following equations:

A) for standard ration:

\[ E = 7.784 + 1.643 \cdot T_{d} - 7.564 \cdot O_A + 0.0018 \cdot D_{h} + 50.674 \cdot (L/D) \]

\[ R^2 = 0.9827 \]

b) for residues ration:

\[ E = 17.791 + 1.925 \cdot T_{d} - 9.363 \cdot O_A - 1.018 \cdot D_{h} + 64.779 \cdot (L/D) \]

\[ R^2 = 0.9789 \]

where: E= the machines energy requirements, kW h/t;
\( T_{d} \)= die thickness, mm;
\( O_A \)= percentage of hole opening area, %;
\( D_{h} \)= hole entry diameter, mm;
\( L/D \)= the ratio between hole length and hole diameter.

3- The influence of geometric dimension of die holes on total losses:

Increasing the L/D ratio, die entry diameter, and die thickness decreased the total losses, while increasing the percentage of die opening area increased the total losses.

347
Fig. (6): Effect of L/D ratio, die entry diameter, Percentage of opening areas, and two rations component on energy requirements.
The obtained results cleared that the increasing in L/D ratio from 1.42 to 2.17 decreased the total losses from 80.69, 53.93, and 4.41% for standard ration, and from 42.70, 38.08, and 31.43% for residues ration at die thickness of 30 mm. by increasing the die thickness up to 35 mm the percent of reduction in total losses increased from 71.67, 61.34, to 44.55% for standard ration, and from 48.14, 42.44, to 35.65% for residues ration at percentage of die opening area from 2.66, 5.33, to 7.99% respectively for die entry diameter of 18 mm.

Refering to the die entry diameter, increasing the die entry diameter from 16 to 18 mm decrease the total losses from 10.85, 13.12, 14.23, to 17.27% for standard ration, and from 8.79, 10.54, 11.75, and 11.48% for residues ration at L/D ratio of 1.42, 1.67, 1.92, and 2.17 respectively, for die thickness of 30 mm.

Consequently, with increasing the die thickness up to 35 mm, the total losses reduced from 11.73, 14.05, 16.65, to 19.56 % for standard ration, and from 11.60, 11.39, 11.75, to 13.30% for residues ration at percentage of die opening area 7.99 %, also the total losses decreased with increasing the die entry diameter from 12 to 20 mm as shown in Fig.(7).

Relatively to increase the percentage of die opening area from 2.66 to 7.99% the total losses increased from 53.76, 74.07, 98.53, to 1333.11% for standard ration, and from 37.02, 45.03, 52.75, to 63.96% for residues ration, at die entry diameter of 18 mm and die thickness of 30 mm, whereas increasing the die thickness up to 35mm, the total losses increased from 61.92, 92.15, 132.76, to 216.94% for standard ration, and from 36.98, 51.93, 63.34, to 77.89% for residues ration at L/D ratio from 1.42, 1.67, 1.92, to 2.17, respectively.

The decrease in total losses by increasing the L/D ratio could be due to the more compact of pellets and high durability with increasing the retention time inside the effective hole. Also the decrease in total losses by increasing the entry diameter could be due to the more flow of ration through the hole and more compact of pellets. In addition the decrease in total losses by increasing the total thickness from 30 to 35 mm could be due to the increase in retention time of ration inside the die hole, it make the ration has more compact inside die hole.

While the increasing of total losses by increase the die opening area could be due to the decrease of retention time of the ration and the decrease of the pressure inside the die, furthermore the increasing of total losses by using the residues ration could be due to the residues ration contents more of fibers which let it easily cracked.

The obtained data from the multi-regression analysis between the total losses and the interaction between the studying parameters produced the following equations:

A) for standard ration:
\[ T_l = 32.058 - 0.222 Th + 0.746 OA - 0.643 D_h - 6.121 \text{ (L/D)} \]
\[ R^2 = 0.9850 \]

b) for residues ration:
\[ T_l = 34.894 - 0.221 Th + 0.738 OA - 0.628 D_h - 6.064 \text{ (L/D)} \]
\[ R^2 = 0.9863 \]

where: \[ T_l = \text{the total losses of pellets, \%}; \]
\[ Th = \text{die thickness, mm}; \]
\[ OA = \text{percentage of hole opening area, \%}; \]
\[ D_h = \text{hole entry diameter, mm}; \]
\[ \text{L/D} = \text{the ratio between hole length and hole diameter} \]

4-The influence of geometric dimension of die holes on pellets durability:

Durability of pellets is considered a good parameter to express the equality specification of pellets, the obtained results cleared that the pellets
Fig. (7): Effect of L/D ratio, die entry diameter, Percentage of opening areas, and two rations component on total losses of pellets
durability increased with increasing the L/D ratio, die entry diameter, and die thickness, while it decreased by increasing the percentage of die opening area, and for both the standard ration and residues ration. The results illustrated that increasing the L/D ratio from 1.42 to 2.17 increased the pellets durability from 7.58, 7.91, to 7.83% for standard ration, and from 7.59, 8.50, to 8.21% for residues ration at die thickness of 30 mm, whereas with increasing the die thickness up to 35 mm the durability increased from 7.26, 7.65, to 7.68% for standard ration, and from 7.32, 7.81, to 7.85% for residues ration at percentage of die opening area from 2.66, 5.33, to 7.99 %, respectively for die entry diameter of 18 mm.

Noticing the die entry diameter, increasing the die entry diameter from 16 to 18 mm, increased the pellets durability from 2.10, 1.25, 2.52, to 1.91 % for standard ration, and from 2.09, 2.13, 1.97 to 1.91% for residues ration at die thickness of 30 mm and L/D ratio of 1.42, 1.67, 1.92, and 2.17 respectively, in addition by increasing the die thickness up to 35 mm, the results showed increasing the durability from 1.93, 1.97, 1.74, to 1.64% for standard ration and from 1.86, 1.86, 1.73, to 1.69% for residues ration and at percentage of die opening area of 7.99 %. Even as increasing the holes entry diameter up to 20 mm the previously conditions of durability also increased as shown in Fig.(8).

Furthermore, increasing the die opening area percentage from 2.66 to 7.99%, the durability decreased from 6.52, 6.22, 6.16, to 6.30% for standard ration, and from 6.41, 6.36, 6.48, to 5.87% for residues ration, at die entry diameter of 18 mm and die thickness of 30 mm, the durability also decreased from 6.59, 6.37, 6.28, to 6.23% for standard ration and from 6.30, 6.06, 5.70, and 5.84% for residues ration by increasing the die thickness up to 35 mm and L/D ratio of 1.42, 1.67, 1.92, and 2.17, respectively.

The obtained data from the multi-regression analysis between the durability of pellets and the interaction between the studying parameters produced the following equations:

A) for standard ration:

\[ D_{U_s} = 41.464 + 0.769 \, T_{d0} - 1.091 \, O_{A0} + 0.656 \, D_{w0} + 8.539 \, (L/D) \quad R^2 = 0.9928 \]

b) for residues ration:

\[ D_{U_r} = 39.798 + 0.727 \, T_{d0} - 1.034 \, O_{A0} + 0.548 \, D_{w0} + 8.314 \, (L/D) \quad R^2 = 0.9890 \]

where:
- \( D_{U_s} \) = the durability of pellets, %;
- \( T_{d0} \) = die thickness, mm;
- \( O_{A0} \) = percentage of hole opening area, %;
- \( D_{w0} \) = hole entry diameter, mm;
- \( L/D \) = the ratio between hole length and hole diameter.

5- The influence of geometric dimension of die holes on pellets bulk density:

Generally, Increasing the L/D ration and die entry diameter and die thickness increased the pellets bulk density, while increasing the percentage of die opening area decreased the pellets bulk density.
Fig. (8): Effect of L/D ratio, die entry diameter, Percentage of opening areas, and two rations component on durability of pellets.
Fig. (9): Effect of L/D ratio, die entry diameter, Percentage of opening areas, and two rations component on pellets bulk density.
The obtained results indicated that, Increasing the L/D ration from 1.42 to 2.17 reduced the pellets bulk density from 8.51, 8.11, to 8.55 % for standard ration, and from 8.94, 11.43, and 8.72% for residues ration at die thickness of 30 mm and die entry diameter of 18 mm. Also increasing the die thickness up to 35 mm, the bulk density decreases from 8.49, 8.59, to 8.52% for standard ration, and from 8.51, 8.60 to 849 % for residues ration at percentage of die opening area 2.66, 5.33, and 7.99 %, respectively.

Focusing on the increasing of die entry diameter from 16 to 18 mm, it was noticed that increasing the pellets bulk density from 0.92, 0.97, 1.04, to 1.02% for standard ration, and from 1.35, 1.3, 1.45 to 1.53% for residues potion at L/D ration of 1.42, 1.67, 1.92, and 2.17 respectively, and percentage of die opening area 7.99% and die thickness of 30 mm.

By increasing the die thickness to 35 mm, the pellets bulk density increased by 1.09, 1.05, 1.03, and 1.09 % for standard ration, and by 1.23, 1.28, 1.26 and 1.13% for residues ration under the previous conditions. Also, it noticed that increasing the die entry diameter from 18 to 20 mm increased the pellets bulk density as shown in Fig. (9).

Simultaneously, the increase of percentage of die opening area from 2.66 to 7.99 % tend to reduce the pellets bulk density from 7.33, 7.53, 7.33 and 7.30% for standard ration, and from 7.32, 7.40, 7.53, to 7.50% for residues ration at L/D ration of 1.42, 1.67, 1.92, and 2.17 respectively, for die entry diameter of 18 m, and die thickness of 30 mm.

By increasing the die thickness up to 35 mm, the pellets bulk density decreased from 7.24, 7.29, 7.24, to 7.21 % for standard ration, and from 7.48, 7.48, 7.52, to 7.5 % for residues ration at the same previous conditions.

The increase in bulk density by increasing the L/D ration could be attributed to the increase in effective hole length and retention time of ration inside the hole. But the increase in bulk density due to increasing the die hole entry diameter could be attributed to the more quantity going in the hole, consequently increasing in the compressions inside the hole.

The obtained data from the multi-regression analysis between the bulk density of pellets and the interaction between the studying parameters produced the following equations:

A) for standard ration:
\[ PD = 0.847 + 0.003 T_{d} - 0.017 O_{a} + 0.007 D_{m} + 0.127 (L/D) \]
\[ R^{2} = 0.9327 \]

b) for residues ration:
\[ PD = 0.734 + 0.003 T_{d} - 0.015 O_{a} + 0.006 D_{m} + 0.113 (L/D) \]
\[ R^{2} = 0.9674 \]

where:  
\( PD \) = the bulk density of pellets, g/cm³;  
\( T_{d} \) = die thickness, mm;  
\( O_{a} \) = percentage of hole opening area, %;  
\( D_{m} \) = hole entry diameter, mm;  
\( L/D \) = the ratio between hole length and hole diameter.

6. The influence of geometric dimension of die holes on pellets hardness:

Generally, the obtained results indicated that pellets hardness increased by increasing the L/D ratio and decreased by decreasing the percentage of die opening area, die entry diameter, and die thickness.
The obtained results illustrated that by increasing the L/D ratio from 1.42 to 2.17 the pellets hardness increased from 6.23, 6.90, to 8.69% for standard rations, and from 9.76, 10.65, to 7.94 % for residues ration at die opening area 2.66, 5.33, and 7.99 %, respectively, for die entry diameter of 18 mm. By increasing the die thickness to 35 mm the hardness increased from 6.47, 4.70, to 7.21% for standard ration, and from 6.84, 7.75, to 5.95 % for residues ration under the pervious conditions.

Furthermore, increasing the die entry diameter from 16 to 18 mm decreased the pellets hardness from 6.88, 5.89, 4.63, to 5.42% for standard ration, and 7.93, 8.80, 9.27, to 8.30% for residues ration at L/D ratio from 1.42, 1.67, 1.92, to 2.17% respectively, and die thickness 35 mm. In addition hardess of pellets decreased from 6.66, 6.24, 5.82, to 5.21% for standard ration and from 9.10, 9.89, 9.34, to 9.28% for residues ration under the previous condition, while increasing the die entry from 18 to 20m increased the pellets hardness as shown in Fig.(10).

The results of the die opening area percentage cleared that the hardness of the produced pellets decreased from 18.42, 17.67, 15.99 to 16.53% for standard ration, and from 17.39, 18.43, 19.82 to 18.76% for residues ration with the increasing of L/D ratio, at die thickness of 30mm. Also, it increased with the increasing of die opening area percentage from 2.66 to 7.99 %. Simultaneously, with increasing the die thickness up to 35mm, the pellets hardness reduced from 18.60, 18.27 to 18.03% for standard ration, and from 17.90, 19.26, 18.52 to 18.58% for residues ration under the conditions of L/D ratio of 1.42, 1.67, 1.92 and 2.17 respectively.

The obtained data from the multi-regression analysis between hardness of pellets and the interaction between the studying parameters could be explained by the following equations:

A) for standard ration:

$$H_p = 108.68 + 0.716 \, T_{b0} - 7.376 \, O_{Ao} + 4.144 \, D_{ne} + 15.788 \, (L/D) \quad R^2 = 0.8964$$

b) for residues ration:

$$H_p = 94.548 + 0.604 \, T_{b0} - 6.159 \, O_{Ao} + 3.002 \, D_{ne} + 13.972 \, (L/D) \quad R^2 = 0.9241$$

where: $H_p$ = the hardness of pellets, N;
$T_{b0}$ = die thickness, mm;
$O_{Ao}$ = percentage of hole opening area, %;
$D_{ne}$ = hole entry diameter, mm;
$L/D$ = the ratio between hole length and hole diameter

**SUMMARY**

Geometrical dimension of die holes are the most important factors influencing on extrusion machine efficiency and pellets quality. Producing 12mm diameter high quality of large animal feed pellets rely the ration components specification, for that the high quality extruded pellets made from residues need different die hole specification comparing with the ration made...
Fig. (10): Effect of L/D ratio, die entry diameter, Percentage of opening areas, and two rations component on pellets hardness.
from standard components. The main objective of the present study is to
bound the optimum dimension of die holes affecting pellets quality and
machine efficiency such as; L/D ratio of (1.42, 1.67, 1.92 and 2.17), hole entry
diameter of (16, 18 and 20 mm), percentage of die opening area (2.66, 5.33,
and 7.99 %) and die thickness of (30 and 35 mm) for two kinds of rations
(residues ration and standard ration).

The obtained results were summarized as follows:

1- the optimum conditions for producing a good quality of pellets from
standard ration were 1.92 L/D ratio, 18 mm hole entry diameter, 5.33 % die
opening area, and 30 mm thickness of die, when the evaluated parameters
(machine productivity, energy requirements, total losses, pellets durability,
pellets bulk density, and pellets hardness) were 0.399 t/h, 114.04 kW
.h./ton, 5.21%, 86.72%, 1.190 g/cm³, and 184.80 N, respectively.

2- the optimum conditions for producing a good quality of pellets from
residues ration were 1.67 L/D ratio, 20 mm hole entry diameter, 2.66 % die
opening area, and 35 mm thickness of die, when the evaluated parameters
(machine productivity, energy requirements, total losses, pellets durability,
pellets bulk density, and pellets hardness) were 0.306 t/h, 153.10 kW
.h./ton, 5.38%, 90.35%, 1.11 g/cm³, and 192.47 N, respectively.

3- The evaluated parameters could be calculated as a function of the studied
parameters according to the empirical equations produced from multi-
regression analysis as follows:

\[ Y_i = a + b X_1 + c X_2 + d X_3 + e X_4 \]

where:

\[ Y_i \quad \text{= machine productivity, energy requirements, total losses, pellets durability,} \]
\[ \quad \text{pellets bulk density, and pellets hardness} \]
\[ X_i \quad \text{= L/D ratio, hole entry diameter (Dha), percentage of die opening area (OA0), and} \]
\[ \quad \text{thickness of die (Th0).} \]
\[ a, b, c, d, e = \text{constants.} \]

REFERENCES


تأثير الأعلاف الهندسية لتشكل مشكل الأعلاف على كفاءة الأكل وجودة العلامة

* د. طاهر رشاد
** د. محمد خطاب

باحث معهد بحوث الهندسة الزراعية - مركز البحوث الزراعية - الجيزة

أستاذ مساعد بقسم الهندسة الزراعية، جامعة الزقازيق

المخالص العربي

تعتبر الصناعة المحلية عصب الاقتصاد القومي وخاصة فيما يتعلق بالإنتاج الزراعي. وتعتبر الأعلاف أحد المحاور الهامة التي تبدأ الإنتاج لها، إذ تعتبر إنتاج الأعلاف المستوردة علامة على المرافق الإنتاجية للمستقبل. فهناك علاجات مختلفة لمعالجة هذه الأعلاف من خلال التصفيح من خلال خلط الأعلاف وحولها إلى مكونات علامة على المرافق الإنتاجية للمستقبل. وتعتبر الإنتاج الزراعي علامة على المرافق الإنتاجية للمستقبل، وتعتبر إنتاج الأعلاف المستوردة علامة على المرافق الإنتاجية للمستقبل. وتعتبر الإنتاج الزراعي علامة على المرافق الإنتاجية للمستقبل.
تهدف هذه الدراسة إلى تحديد الأعوام المثلى لسمك شكل العلف والأعوام الهندسية للوقت لتمكين كل علف.

وقد أوضح النتائج أن اختلاف أعداد ثقوب مشكل العلف يؤثر بوضوح على كفاءة الألواة وجودة العلف.

1- تركيب العلف القياسي: كانت أفرع نسبة العلف المذكور إلى القطر الفعلي للقلب هي 0.92 وقطر مدخل القلب 18 ومساحة مخرج العلف 53.3% وسمك كلي لشكل العلف 30 مم وأعطت النتائج التالية:

- (0.399) من لائحة المقاومة للصلابة - (114.04 كيلو فات. ساعه/م.م للطاقة المستنثة - 2.52% للقادر.

2- تركيب العلف النقي (مجموعة مخفف): كان أفرع نسبة السمك المذكور إلى القطر الفعلي للقلب هي 1.67 وقطر مدخل للقلب 20 ومساحة مخرج العلف 2.66% وسمك كلي لشكل العلف 35 مم وأعطت النتائج التالية:

- (0.306) من لائحة المقاومة للصلابة - (155.1 كيلو فات. ساعه/م.م للطاقة المستنثة - 5.38% للقادر.

و ثم استنتاج معدات متعددة الحد: يتوزع القشر في نواة العلف في (المباشرة - القيمة المستنثة - القادر - مقدمة).

المقدمة: 

\[ Y_i = a + b X_1 + c X_2 + d X_3 + e X_4 \]

حيث:

- سماك شكل العلف 
- نسبة السمك المفردة في شكل العلف 
- قطر نقطة دخول العلف في شكل العلف 
- نسبة الطول للقطر لتمكين كل علف

المقدمة: 

1.359