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(Review Article)

Pelleting dies – design, material, geometry of pressing channels

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Abstract

The paper deals with the specific field of the design of pelleting tools with a focus on pelleting dies. It focuses in great detail on the different geometries of the press channels and their significance. It also approaches the field of material engineering in the design of these tools. The published information is based on many years of experience, knowledge, and professional data about pelleting tools acquired by the authors during many years of design practice in the field of research and development of pelleting machines and tools. The information provided is intended to explain this specific field and to assist designers in the design of pressing tools.

Keywords: Pelleting die; Flat die; Ring die; Pelleting tools; Densification; Pressing channels

1. Introduction

Pressing tools are the powerful core of the entire technological line for the production of solid biofuels. Not only the functionality of the compaction machines, but above all the quality of production and the economy of the whole technology depend on their design, material, geometry, surface treatment or chemical-thermal treatment, accuracy and precision of assembly, and last but not least also wear resistance. One incorrectly selected parameter of pressing tools can be the cause of poor quality production, but also an irreversible accident of the whole pelleting machine. It is therefore necessary to approach the design of pressing tools and their individual parameters with maximum responsibility. The prerequisite must be knowledge of the entire biomass pressing process and the influence of each parameter of the pressing tools [1].

As already mentioned, pelleting pressing tools are exposed to similar operating conditions: high compacting pressure, relatively high temperature, high degree of abrasion by the pressed material, direct influence of humidity and greater or lesser impact of shocks (depending on the working principle of the pelleting machine).

There is a lot of research works that deals with the study of individual design parameters of tools and parameters of the biomass pressing process and their impact on the final quality of production, energy consumption as well as the level of wear of the tools themselves. Papers [2,3,4,5] deal with the influence of design parameters of pressing tools on the pressing process. The research results of the influence of pellet die design on its wear and energy consumption are presented in [6,7].

2. Design of pelleting dies

Although the development of science and technology in the world still brings new principles of compaction machines, biomass pelleting for the production of solid biofuels is basically the same principle, by extruding a suitably treated raw

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material under suitable technological conditions. At present, a pair of tools are used for pelleting technology in almost every case, namely cylindrical or conical rolls, which press and extrude the raw material through the holes of flat resp. ring die by their rolling. The compacting pressure on the raw material exerted by the pressing rolls is directly proportional to the resistance to overpressure of the raw material in the individual pressing channels of the die. The size of the resistance called the back pressure is given by the geometry of these channels. The pellets are formed by the action of the pressing roll pressure and the back pressure in the die channels. The pellets are broken off to the required length after pressing. In order for the pressing pressure in the channels to be constant, it must be ensured that the raw material is filled evenly over the entire surface of the die. [8]

In practice, there are many manufacturers and types of pelleting machines. However, pelleting machines for the production of solid biofuels, especially medium and higher outputs (from about 200 kg/h.) use only dies of flat and ring design.

Flat dies (Fig. 1) are characterized by a simpler design. It is a disc with drilled holes of precisely specified geometry. They are produced in smaller dimensions than ring dies, they have a lower weight, which is an advantage especially during exchange and handling. They are easy to maintain and clean. Their biggest advantage compared to ring dies is their much lower production costs. [1]

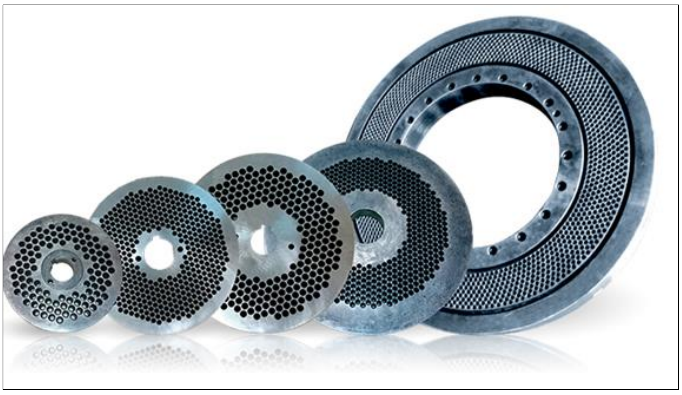


Figure 1 Design of flat pelleting die

Ring dies (Fig. 2) are characterized by a much more complex construction, larger dimensions and weight, which also results in high production costs. Nevertheless, they are much more represented in practice due to their high hourly outputs with lower energy consumption compared to flat dies, they have high strength, less wear and longer service life due to the principle of tool kinematics.

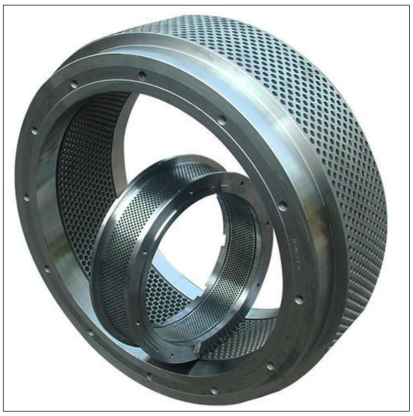


Figure 2 Design of ring pelleting die

Flat die pellet presses are characterized by a compact design with a vertical main axis of rotation, high variability, but lower hourly production output and lower efficiency. Their principle is based on the relative movement of the die and the pressing rolls. Depending on the manufacturer, power and type of press, the drive is solved by means of a belt transmission or by means of a helical gearbox, or for higher outputs also by using two helical gearboxes at the same time. Depending on the manufacturer, either the die or the central shaft with the rolls is driven. Their number varies from 2 to 5 depending on the power of the press. With the correct assembly and definition of the mutual position of the tools (dies and rollers), there is no mutual contact during the operation of the machine due to the reduction of the wear rate. [9] Rolling of the rolls occurs only due to the friction caused by filling the pressed raw material into the pressing space between the tools from the top. At the same time, the raw material is pressed and pressed into the pressing channels of the die. The selected geometry of these channels is responsible for the amount of resistance to extrusion of the raw material, which increases the compacting pressure and at the same time the density and strength of the pellets. The length of the pellets after extrusion is defined by the adjustable position of the breaking knives.

The principle of operation of pellet presses with a ring die consists in the forced rotation of the die with a horizontal axis. This is driven mostly by a belt drive and, depending on the power of the press, by one or two electric motors. Two to three pressing rolls are rotatably mounted on a fixed stirrup inside the die. There is no mutual rolling between the rolls and the die without pressed material. The gap between them is adjusted by eccentric mounting of the roll axis on the. The filling of the raw material into the pressing space is more complicated due to the horizontal axis of rotation of the die. The raw material must be distributed evenly under all rolls in order to eliminate the radial load of the embedded roll support bracket. The raw material enters the pressing space and is carried by the centrifugal force in an even layer over the inner surface of the die. At the entrance between the roll and the die, this raw material is pressed and extruded through the pressing channels in the die to its outer surface in the form of pellets. Subsequently, the pellets of the required length are broken off with knives.

3. Geometry of pressing channels of pelleting dies

The geometry of the pressing channels itself plays the most important role in the construction of the pelleting die. The quality of the pellets, as well as the energy efficiency of production, depends on their distribution, shape, specific dimensions and overall geometry. At the same time, the geometry of these channels is directly dependent on the type and properties of the pressed material, to which it must be adapted.

It is clear from Figure 3 that the pressing channels consist of three basic parts: countersunk part, effective length (so-called effective thickness of the die) and relief on the output part. The working surface of the die is actually the inner surface of the pressing channel in the die. Its geometry is very important not only due to the fact that it directly affects the size of the pressing pressure, but also ensures the retention time of the pressed raw material under pressure, so that the necessary bonds can be formed in the pellet.

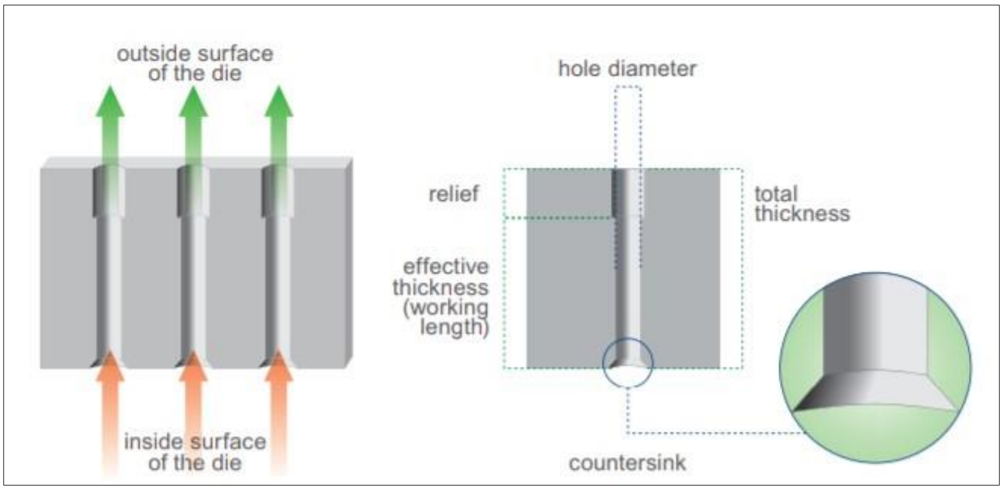
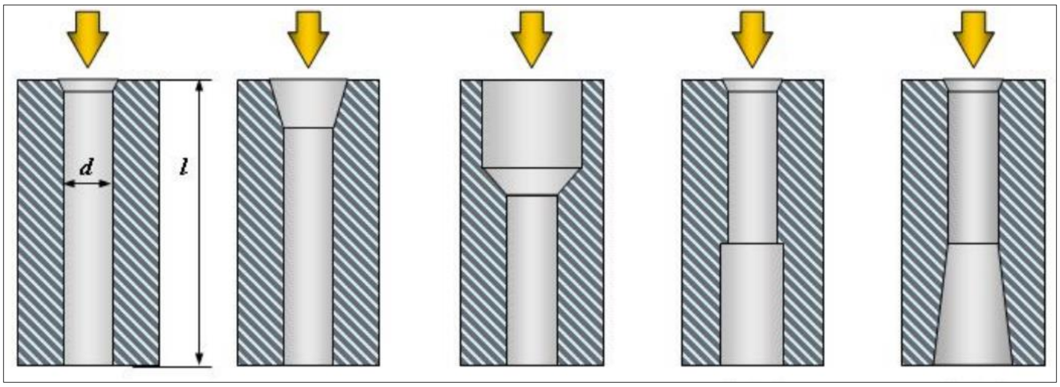


Figure 3 Specific parameters of pressing channels of pelleting dies [10]

The basic parameter of pressing channels is their compression ratio. It is the ratio between the effective length of the channel and its diameter. Above all, the quality of the pellets depends on this ratio. The value of the compression ratio varies depending on the type of pressed material. As the value of the compression ratio increases, the resistance against pushing the raw material through the channel increases, which is reflected in an increase in the pressing pressure and at the same time an increase in the density of the pellets.

The goal in designing the optimal channel geometry is to achieve the correct compression ratio to achieve high-quality extrusions, optimal resistance to extrusion to ensure sufficient pressing pressure and the best possible energy efficiency of the process. The very geometry of the pressing channels varies depending on the properties of the pressed raw material.

The basic geometrical parameters of the pressing channels/chambers of the pelleting dies are shown in Figure 4.



a) cylinder *b) intake cone* *c) stepped channel* *d) relief bore cylindrical* *e) relief bore conical*

Figure 4 Basic geometric parameters of the pressing channels of the pelletizing dies [11]

3.1. Straight cylindrical channel

The basic parameters of the pelleting die include the effective thickness of the die (or the effective length of the pressing channels). In the case of straight cylindrical pressing channels, their effective length is equal to the total thickness of the die. They are characterized by a constant hole diameter along the entire length, with the exception of the conical entry. Dies with straight channels are intended for pressing e.g. wood matter or biomass requiring higher pressing pressure to create high-quality pellets. This geometry is the simplest to manufacture. Flat dies with straight channels even have the advantage of being double-sided, doubling their lifespan.

3.2. Normal inlet countersink

The inlet of the channels in the die have a countersink, guiding material into the holes. Countersinks can have different shapes. In the case of a conical shape with an apex angle of 55-60°, we are talking about a normal countersink (Fig. 5) designed, for example, for wood pelleting. The shape and angle of the recess is very important, because too deep countersink can lead to strong precompression and some types of raw materials will cause clogging of the entrances to the channels. This risk is especially at the beginning of pelleting, when the pressing temperature is low and the resistance of the raw material against extrusion is higher.

Figure 5 Normal inlet countersink of pressing channels

3.3. Taper inlet

With some types of pressed raw material, it is not possible to achieve the necessary compression ratio to derive the required pressing force due to the limited constructional thickness of the die, which results in the production of low-quality friable pellets with low density. In this case, it is possible to modify the geometry of the pressing channels. It is possible to increase the pressing pressure by implementing taper inlets into the channels and by increasing the depth of the cone and its apex angle. For many types of phytomass and feed, dies for pellets with a diameter of 6 mm are produced with a relatively large depth of the entrance cone (15 to 25 mm) to avoid the need to increase the thickness of the die.

3.4. Well inlet

The stepped inlet (called also well inlet) represents the most extreme form of precompaction in the pressing channel. The shape of such an inlet consists of a cylindrical hole with a larger diameter than the continuation of the chamber. The depth of such an inlet can be up to 30% of the total length of the channel, and its diameter can be up to twice the diameter of the channel. Such stepped inlet geometry is used in the following cases:

- if additional compression is needed due to the high content of lubricants in the raw material (especially in feed mixtures, pelletizing waste from oilseed processing, etc.),
- in case of need to increase the compression to create a higher necessary pressing temperature for the production of stronger pellets.

A shallow stepped inlet is often used when pelleting material of a larger fraction, which would be difficult to get into small channels.

3.5. Outlet relief

In order for the die to have guaranteed strength and to prevent deformations during pressing, it is often made thicker than required by the compression ratio or the effective length of the pressing channels. After that, holes of a larger diameter are drilled on the outlet side of the channels, to such a depth that the required value of the compression ratio is maintained. In the case of the existence of a relief, the effective thickness of the die is equal to the total thickness reduced by the length of the relief. The geometry of the relief (Fig. 6) is either stepped or reversed, i.e. it can either have the shape of an offset cylinder of larger diameter or a conical shape increasing towards the outlet of the channel. Cylindrical offset is used exclusively to achieve the required value of the compression ratio with larger die thicknesses. The reverse relief has the shape of an expanding cone and is used in the pelletization of pliable soft materials such as alfalfa, some types of phytomass or feed. The wear of the pressing channels increases the diameter of the hole of their effective length, which reduces the compression ratio. This would lead to a reduction in the quality of the pellets. If reverse relief geometry is applied, then as the diameter of the channel increases due to wear, its effective length also increases and the compression ratio is maintained.

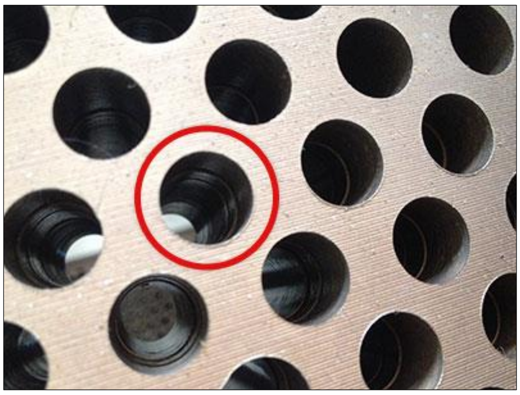


Figure 6 Detail of the outlet relief of the pelleting die

The pelleting die can contain pressing channels of the same geometry (straight pressing channels, pressing channels with the same relief) or different pressing channels with different relief (referring to ring dies) (shown in Fig. 7).

- Standard die – all the channels have the same effective thickness.

- Standard relieved die – all channels have the same effective thickness, but the discharge side of the channel is enlarged. The primary purpose for this die is to add strength to the die without making the channel depth thicker.
- Standard variable relief die – all channels are the same except the two or three outside rows of the die. The number of rows to be relieved varies by die manufacturer. Certain products to be pelletized will have a tendency to squeeze out to the side of the die. When this happens the two or three outside rows become plugged and as much as 25% of the die effectiveness is lost.
- Staggered relief die – this die serves the same purpose as a standard variable relief die. The effect of the variable relief in the two to three outermost rows of channels is amplified by the next two to three rows of channels with less relief towards the middle of the die width. [12]

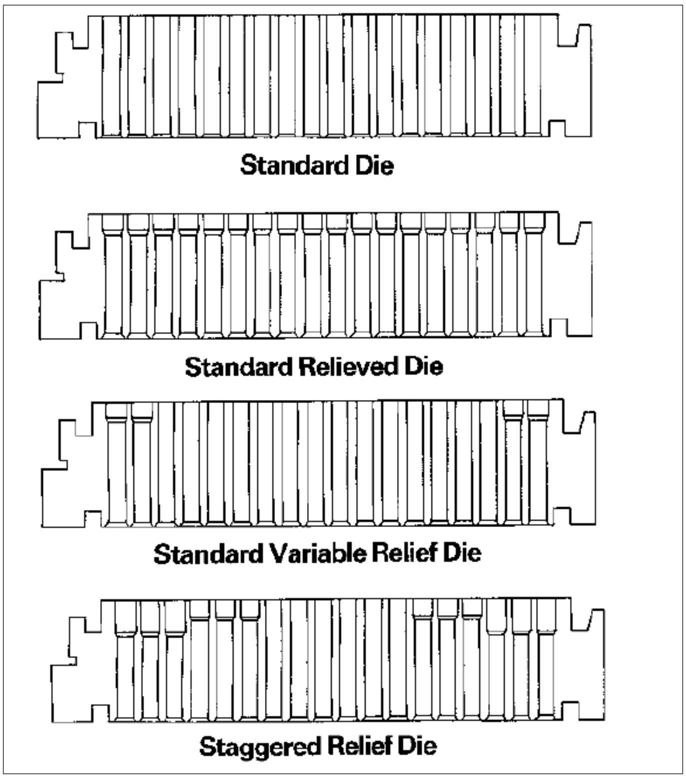


Figure 7 Dies with outlet reliefs of different shape and function [12]

As mentioned, the shortening of the channels through the relief is realized in order to increase the strength of the pelleting die by increasing its thickness. However, the strength of the die can also be significantly influenced by the density of the distribution of channels on its surface. Holes in dies are usually drilled in three basic patterns:

- The dense hole pattern provides a more open die area (around 43%) and higher output. With more open die surfaces, a longer retention time of the material under pressure is ensured to create stronger pellets, which reduces energy consumption per ton of pelletized raw material and helps increase production efficiency. At the same time, with a larger open area for the same thickness, the strength of the die decreases.
- The pattern with a sparse channel distribution provides a smaller open die area (approx. 32%) but higher strength.
- The standard channel layout provides a compromise between die open area and pressing force.

Drilling channels is very difficult for manufacturing, especially on ring dies, and mainly with more complex geometry of the hole containing relief at the outside. In that case, it is necessary to drill all holes from both sides of the die. If it is a graded geometry, several different tools are also needed. The production complexity of the geometry of the press channels is significantly reflected in the die price. Single-purpose drilling machines (Fig. 8 and Fig. 9) are used to machine the pressing channels of ring dies.

Figure 8 Drilling the relief on the outside surface of the die [13]

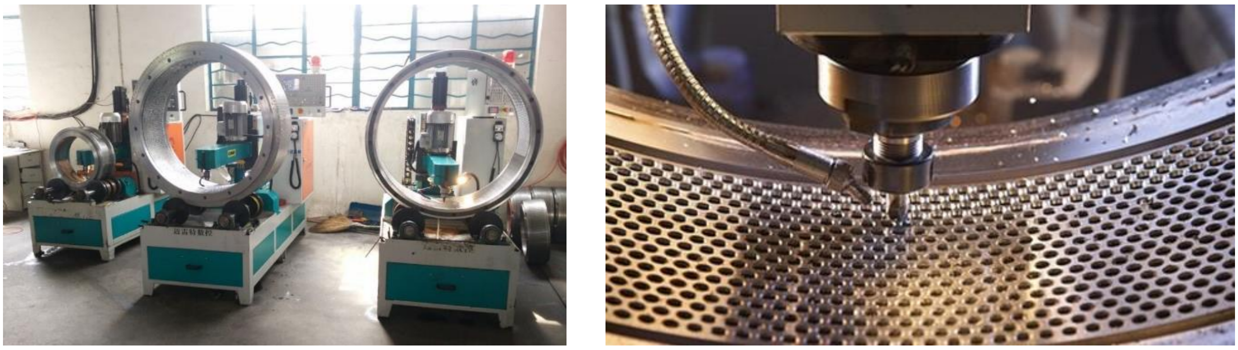


Figure 9 Drilling a countersink on the inside surface of the die

4. Material of pelleting dies

In operation, pelleting dies must resist abrasion due to the pressed raw material, corrosion caused by water, steam and chemical action, and breakage due to high force and thermal stress during the pellet pressing process. The optimal die combines high resistance to abrasion, fracture and corrosion with maximum productivity.

Choosing the right material is very important. Dies for different types of pelletized raw materials are made from steels with appropriately selected carbon and chromium content and heat treated to the required properties. Each of the materials listed below has properties that make it more suitable for certain applications [14]:

- Dies made of alloy steel are designed for highly abrasive applications and are the most resistant to cracking. These dies are generally less expensive than stainless steel or high chromium steel dies. Producers prefer them mainly for their good resistance to abrasion and strength. Dies have a cemented and hardened surface, while the core remains tough. Considering the number of alloy steels, some alloying elements and their positive properties for die material will be listed:
    - nickel – increases strength,
    - manganese – increases resistance to wear and shocks,
    - chromium - can affect mechanical properties such as resistance and hardness, along with physical properties such as resistance to corrosion and oxidation. Chromium carbides are formed during the heat treatment process by combining chromium and carbon atoms, which increases wear resistance.
    - molybdenum - reduces fragility.
- Stainless steel dies provide corrosion resistance and good wear resistance for moderately abrasive materials. Stainless steel often is chosen for "all-purpose" dies. There are normally the highest quality, longest lasting type of dies but also the most costly. The die surface is hardened to increase hardness and abrasion resistance.
- High chrome dies provide the most corrosion resistance of the different die materials. Due to the high chromium content and the resulting good sliding properties, the start of pelleting is very easy and the dies enable high production capacities. However, the high chromium content usually does not provide sufficient resistance to extrusion to generate the necessary pressing forces. Therefore, in order to achieve the desired quality of pellets,

it may be necessary to increase the effective thickness of the die and thus also the compression ratio of the pressing chambers. Dies made of this material are hardened in the entire cross-section

5. Conclusion

The aim of this paper is to summarize the knowledge, experience and professional information about pelleting tools that the authors have acquired during many years of design practice in the field of research and development of pelleting machines and tools. The information provided is intended to explain this specific area and to assist designers in the design of pressing tools. The functionality of compaction machines, but above all the quality of production and the economy of the entire technology, depends especially on the design of pelleting die, its material, geometry, surface treatment or chemical and heat treatment, correctness and accuracy of assembly, and last but not least, resistance to wear.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declares that there is no conflict of interest in their research study.

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