Analysis and Assessment of Wear and Failure of Pellet Press Tools

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ABSTRACT: *Pellet presses are progressive and efficient machines for the production of solid high-grade biofuel for automated combustion devices, as well as for the processing of feed mixtures and fertilizers. Pelleting tools are powerful parts of these machines, but they are the fastest subject to wear or failures. The aim of the paper is to summarize the authors' knowledge, findings and personal experience in the field of pelleting tools and their malfunctions. The paper includes a comprehensive categorization of failures, identification of their origin and interpretation of the impacts of failures of pelleting tools. Investigating the causes of tool wear or failure and improving operating conditions has a fundamental impact on performance and production quality, as well as on reducing energy consumption and production costs. The published information is of great practical importance for the development of pelleting technology and for the development of the design of pressing tools.*

Keywords: *pelleting, pellet press, pelleting tools, pelleting die, tool wear, tool failure*

Date of Submission: 20-12-2022 Date of acceptance: 02-01-2023

I. INTRODUCTION

Global production of wood pellets increased from 5 million tonnes in 2005 to 32 million tonnes by 2017 [1,2]. Global wood pellet production reached 36 million tonnes in 2018, and almost 40 million tonnes in 2019. [3] Figure 1 shows an evolution of global wood pellet production. Expected production will reach more than 60 million tonnes by 2025 [4]. In line with the forecast, the European Union has set target to obtain that 27% of the total energy consumption in 2030 is produced from renewable energy sources [5], and to attain this target, biomass plays an important role [6].

Production technology must ensure high and consistent quality of wood pellets. The quality of pellets is defined by a number of specific parameters, which are defined by a set of international standards [7]. 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.

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). Therefore, it is necessary to take into account all process parameters as well as geometric requirements in their design. 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 [8,9,10,11] 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 [12,13]. The research presented in [14] analyzes in detail the damage of the pelleting dies.

II. PELLETING OF BIOMASS

Biomass pelleting technology is a progressive way of compacting crushed and dried material by extrusion through a pressing die. In this technology, the feedstock with suitable fraction size and moisture content is forced through holes in the die by pressing tool. At very high pressure and associated temperature, the lignin component of the biomass plasticizes and takes over the function of a binder. The pellets are very hot and plastic after passing and cutting from the pressing tool. They gain hardness and mechanical resistance only after cooling. The raw material is compressed with or without the addition of an additive as a binder (depending on the type of material being pressed). The pelleting technology is characterized by the fact that at one point in time several compacts (pellets) are formed, which have a cylindrical shape.

Each time a press channel passes a roller, feedstock is compressed and pressed into the channel. As material is pressed into the channels, cylinders of compressed material are extruded from the outside of the die, where blades break them into pellets. Frictional heating in the die causes the pellet temperature to reach 90–105°C [15,16,17]. The heating causes moisture to flash off from the pellets, and thereby drying the pellet. The final moisture content of wood pellets is in the range of 7–10% on wet basis (w.b) [18]. In order to fulfill the standard requirements for wood pellets, the moisture content of the final pellets must be below 10% (w.b). [19]

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 chambers of the die. The size of the resistance called the back pressure is given by the geometry of these chambers. The pellets are formed by the action of the pressing roll pressure and the back pressure in the die chambers. The pellets are broken off to the required length after pressing. In order for the pressing pressure in the chambers to be constant, it must be ensured that the raw material is filled evenly over the entire surface of the die.

III. PELLETING TOOLS

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. [20]

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. In order to better understand the differences between these types of dies, it is necessary to explain in detail the working principle and kinematics of individual structures.

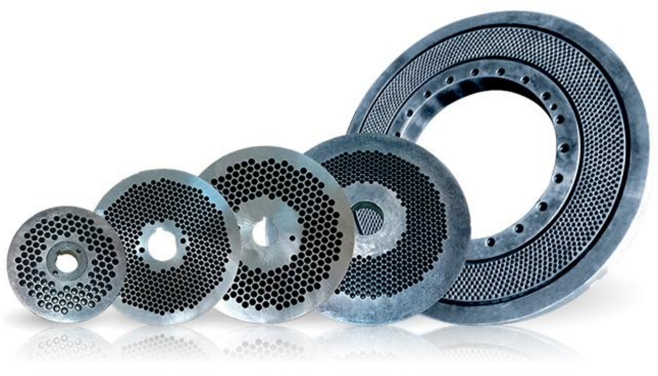

Fig. 1 Design of flat pelleting dies

Fig. 2 Design of ring pelleting dies

The design of the pressing rolls varies depending on the manufacturer, the design of the machine, the power of the machine, or the type of pressed raw material. In general, these are rollers rotating freely at the end of an embossed support shaft. It should be emphasized that a minimum gap is set between the rolls and the die to prevent metal contact. The rotation of the rolls occurs only under the effect of friction due to the filling of the pressed material between the die and the rolls. The rotation of the cylinder on the shaft at high radial loads is ensured by a pair of tapered or barrel bearings.

Flat die pelleting presses usually have from 2 to 5 rolls evenly distributed on the die surface (Fig. 3). Their number depends on the die area and the power of the press. Their construction is simpler, as the bearings are mounted directly on the free end of the support shaft. [20]

Fig. 3 Pressing rolls arrangement of flat die pelleting machine

In the case of pelleting machines with ring die, the number of pressing rolls is usually two to three (Fig. 4 and Fig. 5). Three rollers are usually used for high-performance presses and large die diameters. The design of the bearing is more complicated. An eccentric is mounted at the free end of the support shaft to define the exact relative position of the roll and die. At the eccentric, there are a pair of bearings inserted into the working shell of a hollow cylinder. [20]

Fig. 4 Pressing rolls arrangement of ring die pelleting press

Fig. 5 Construction of pressing rolls of the ring die pelleting press

The work surface of the rolls that comes into contact with the pressed raw material must have a specific "tread" geometry in order to effectively pull the raw material under the roll and press it and extrude it through the die. There are many patterns and configurations of the outer shell of the rolls, their use differs from the type of pelleted material and the manufacturer. The tread pattern can be wavy with open or closed end grooves, wavy spiral, hole, protrusion, combined, etc.

IV. FAILURES OF PELLETING TOOLS

During normal operation, there is a constant frictional force between the tool and the pressed raw material. The existence of this friction gradually wears out the die as well as the rolls and reduces the efficiency of the entire pelleting process. The standard for measuring the level of die wear is the hourly machine output, i.e. weight of pellets produced per hour. Due to the high production cost of dies, increased wear significantly affects the production costs of pellets. Therefore, it is necessary to analyze in more detail the reasons for the loss of die efficiency, its wear and failures.

LOSS OF EFFICIENCY OF THE PELLETING DIE

There are three types of reasons for the loss of efficiency of the pelleting die. The first reason can be the wear of the inner surface of the pressing channel and an increase of its diameter, which will produce pellets with a larger diameter outside the limits of the required size. The second reason is the roughening of the inner surface of the channels due to abrasive wear, which causes higher friction in the channels and thus slows down the extruded material. Such wear leads to a decrease in the hourly production of the machine or even to a stoppage. The third reason for the loss of efficiency or of the functionality of the die is the wear of the surface of the pressing channels, thereby increasing their diameters, which leads to a reduction in the supporting cross-section of the die material between the channels. This happens at the same time as the first mentioned reason and it can happen until the time when, due to the weakening of the supporting part of the die, a crack occurs in the weakest place between the individual channels and a fracture occurs. By cushioning such a damaged die, the pressing force is reduced and the efficiency of the die is lost, thus reducing the production of the machine. The reason for the emergence of these three situations, when a loss of die efficiency occurs, is primarily the wear of the pressing channels and, secondly, material fatigue in the form of fatigue fracture.

ABRASIVE WEAR

There are many causes of abrasive wear on pelleting tools. They can be divided into normal and abnormal wear [21]. The cause of normal wear is mainly the type and composition of the pressed raw material, the size of the pressed fraction and the method and quality of conditioning the raw material. During the normal wear, there is uniform wear of the pressing channels in the axial direction. Thus, there is an increase in the diameters of the chambers and a thinning of the support walls of the die between the pressing chambers. The cause of the abnormal wear is mainly small or no gap between the die and the rolls, the wrong angle of the spreader setting, which leads to an unevenly spread layer of the raw material entering under the rolls and subsequently to uneven wear of tools, or metal particles from worn tools entering the pressing chambers. These causes lead to rapid and uneven wear, especially of the die, but also of the rolls. When pelleting fibrous material, it is advisable to add some kind of lubricant to reduce the friction force between the raw material and the die, which prevents clogging of the pressing channels and gives the pellets a smooth surface. [22]

SIGNS OF WEAR

Depth of surface wear

The most noticeable and important trait of any worn die is the depth of the surface wear. The depth of surface wear is defined as the perpendicular distance to the die face from the horizontal plane that marked the original die face surface. Wear depth values are measured at three locations in the transverse direction of the die – in the exact center of the working surface of the die and in the third rows of chambers from each side. The only exception is the existence of an extremely deep wear band, in which case the measurement would be made at the deepest point. The depth of wear measurement gives important information concerning feed distribution by evaluating which portion of the ring die is worn the deepest. This measurement can also identify worn wipers and deflectors, as well as unevenly worn pressing rolls. [22] The surface wear of the pressing tools is shown in Figures 6 to 10.

Fig. 6 Deep wear of the die surface

Fig. 7 Uniform abrasive wear of flat die surface

Fig. 8 Detail of the wear of the perforated surface of the pressing rolls

Fig. 9 Detail of deep wear of the grooved working surface of the roll

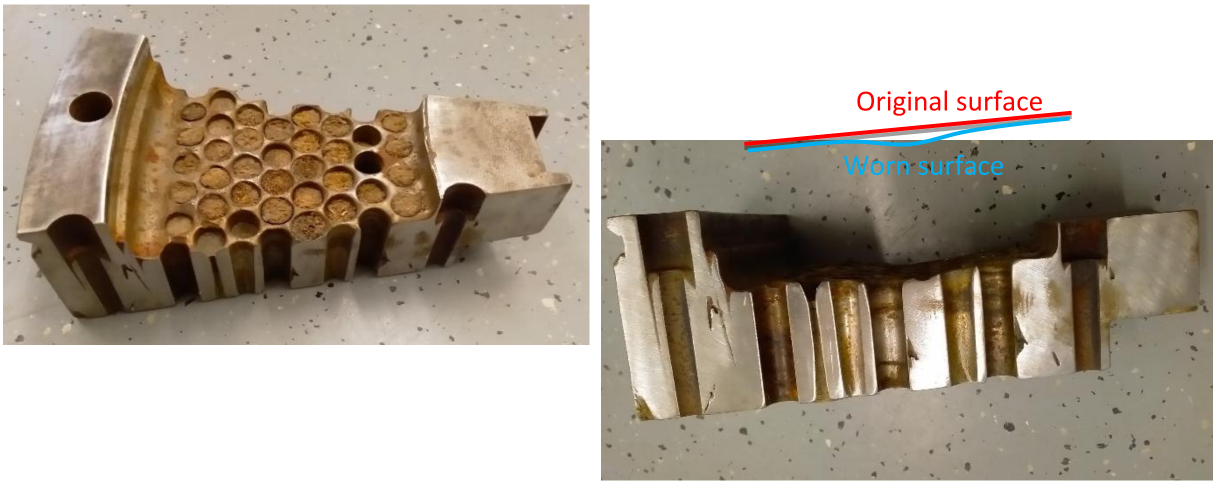

Fig. 10 Research on the wear depth of a flat pelleting die

Rollover

Rollover is the condition of the die face when the inlet parts of the pressing chambers begin to close by rollover (Fig. 11). This condition has serious impacts on both pellet quality and throughput of the die, usually lowering both. Rollover is caused when the force acting on the face of the die exceeds the toughness of its material. Roller adjustment and certain types of row material exert excessive stresses on the die face, initiating rollover. [22] The probability of occurrence of this type of die failure increases with increasing surface wear depth for dies with only a surface hardened layer (alloy steel dies).

Fig. 11 Wear of the die surface by rollover

Honeycombing

This apt name – honeycombing – belongs to the result of abrasive wear of the die, when the pressed raw material evenly wears the entrance part of the pressing chambers on the front surface of the die (Fig. 12). This type of wear can result in a serious reduction in the thickness of the die support material between the pressing chambers and its subsequent cracking. The formation of honeycomb in a fine form on the surface of the die is a sign of a quality die and is characteristic of a material with a high chromium content.

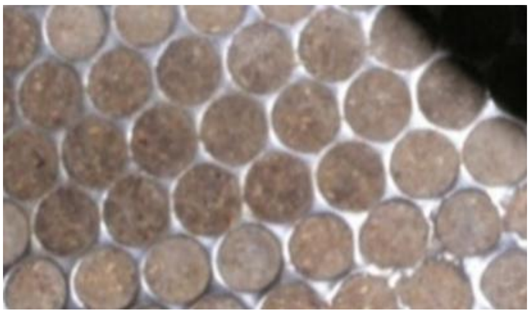

Fig. 12 Wear of the die surface by "honeycombing"

Pitting and Scoring

Pitting is a state of wear of the pressing channels caused by corrosion, which is the result of the action of moisture and heat in combination with the pressed raw material (Fig. 13). Pitting looks like small spots with micro-corrosion that gradually get larger. Pitting increases the resistance to extrusion and thus reduces the permeability of the die. It can often reduce pellet quality due to the rough surface of the pressing channels. [22]

Scoring has the appearance of longitudinal lines on the inner surface of the pressing chambers [22]. These grooves are caused by highly abrasive pelletized raw materials, which damage its surface when passing through the chamber. Very often scoring occurs as a result of previous pitting. Then it has the shape of a comet, the origin is a pit and the tail is caused by scoring. Heavy scoring reduces the permeability of the die and decreases the quality of the pellets.

Fig. 13 Damage to the pressing channels of the die by pitting

FATIGUE FRACTURE

The pelleting die is a tool whose construction is weakened by a number of pressing chambers. It performs its function in adverse conditions, under the influence of high force loading by pressing rolls, under the influence of frictional forces both on the surface of the die and inside the pressing chambers, and all this in a corrosive environment at a raised working temperature. However, it is not the high pressing pressure that reduces its service life, but primarily material fatigue. The die is loaded with an alternating load due to the rolling of the pressing rolls, which leads to a fatigue fracture (Fig. 14). This failure can be partially prevented already during the design of the die. In the case of flat die, it is advisable to increase its thickness. In view of the stress curve of ring dies, increasing not only the thickness and width, but also the diameter of the die helps. These design changes can improve die bending resistance and manufacturing efficiency. If the dimensions of the die are unchanged, its strength can be positively influenced by changing the drilling pattern of the pressing chambers or by appropriate heat treatment.

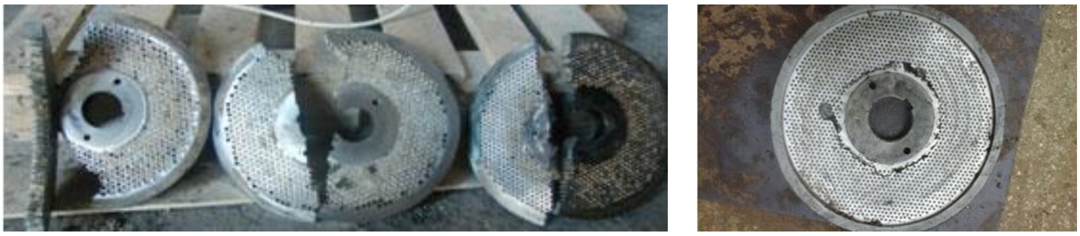

Fig. 14 Damage to the flat die by fatigue fracture [23]

Fig. 15 Damage to the ring die by fatigue fracture [14]

Just like the pelleting die, the pressing rolls are subject to high force loads, friction and alternating loads. These factors result from normal wear of shells, through abnormal uneven wear, to fatigue fracture of shafts or bushings and hubs (Fig. 16).

Fig. 16 Different types of wear and damage to the pressing rolls [23]

V. CONCLUSION

The aim of the paper is to summarize the authors' knowledge, findings and personal experience in the field of pelleting tools and their malfunctions. The paper is devoted to the complex categorization of failures, identification of the origin and interpretation of the effects of failures of pelleting tools. Investigating the causes of tool wear or failure and improving operating conditions has a fundamental impact on output and production quality, as well as on reducing energy consumption and production costs. The published information is of great practical importance for the development of pelleting technology and for the development of the design of pressing tools.

ACKNOWLEDGMENTS

The paper is a part of the research done within the project APVV-19-0607 "Optimized progressive shapes and unconventional composite raw materials of high-grade biofuels" funded by the Slovak Research and Development Agency.

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