World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(REVIEW ARTICLE)

Design of pressing tools for pelleting machines

Miloš Matúš [1, *], Peter Križan [1], Ľubomír Šooš [1] and Viliam Veteška [2]

[1] *Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. Namestie slobody 17, Bratislava, 812 31 Bratislava. Slovakia.*
[2] *ECPU s.r.o., Streženická cesta 1025/5, 020 01 Púchov. Slovakia.*

World Journal of Advanced Engineering Technology and Sciences, 2021, 04(01), 052–062

Publication history: Received on 19 October 2021; revised on 25 November 2021; accepted on 27 November 2021

Article DOI: https://doi.org/10.30574/wjaets.2021.4.1.0086

Abstract

The growing global demand for energy, as well as the global demand for a higher share of the use of renewable energy sources, is leading to intensive development of the production of solid biofuels in the form of pellets. Biomass pelleting technology is successfully used to produce solid high-grade biofuel in the form of pellets. This biofuel is currently an important trade item in the energy markets. The development of pelleting technology also brings higher demands on pelleting machines and tools. Pressing tools are the powerful core of the entire technological line for the production of solid biofuels. The paper deals with biomass pelleting technology and describes the requirements and limits of this technology. It focuses in great detail on the pressing tools of pelleting machines. The work examines in detail the design of pressing dies and pressing rolls. The above knowledge are based on the personal experience of the authors as designers of pelleting machines and tools. The published information is of great practical importance for the development of pelleting technology and for moving forward in the design of pressing tools

Keywords: Pelleting; Pelleting press; Pelleting tools; Pelleting die; Densification; Biomass

1. 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]. In pellets production, the configuration and operation of pellet mills highly affect the process efficiency and pellet properties [8,9,10]. The feedstock and process characteristics demand the pellet mills to be tuned for each production, with respect to die design and operational settings [11]. For efficient production of pellets from different types of raw materials, the right choice of used pressing tools is necessary. The design of pressing tools and their partial construction parameters fundamentally affect the final quality of production and the economy of the whole process.

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

* Corresponding author: Miloš Matúš
Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava. Namestie slobody 17, Bratislava, 812 31 Bratislava. Slovakia.

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.

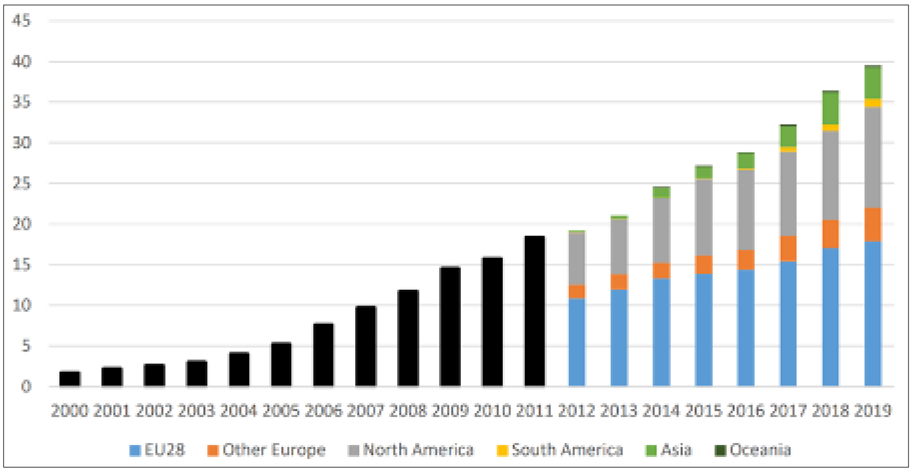


Figure 1 Evolution of global pellet production (million tonnes) [4]

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). 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 [12,13,14,15] deal with the influence of design parameters of pressing tools on the pressing process. The research presented in the studies [9,16,17] is focused on the influence of technological parameters of biomass pelleting on the final quality of pellets. The research results of the influence of pellet die design on its wear and energy consumption are presented in [18,19].

2. Biomass pelleting technology

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 (Fig. 2).

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 [20,21,22]. 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) [23]. In order to meet the standard requirements for wood pellets, the moisture content of the final pellets must be below 10% (w.b). [24]

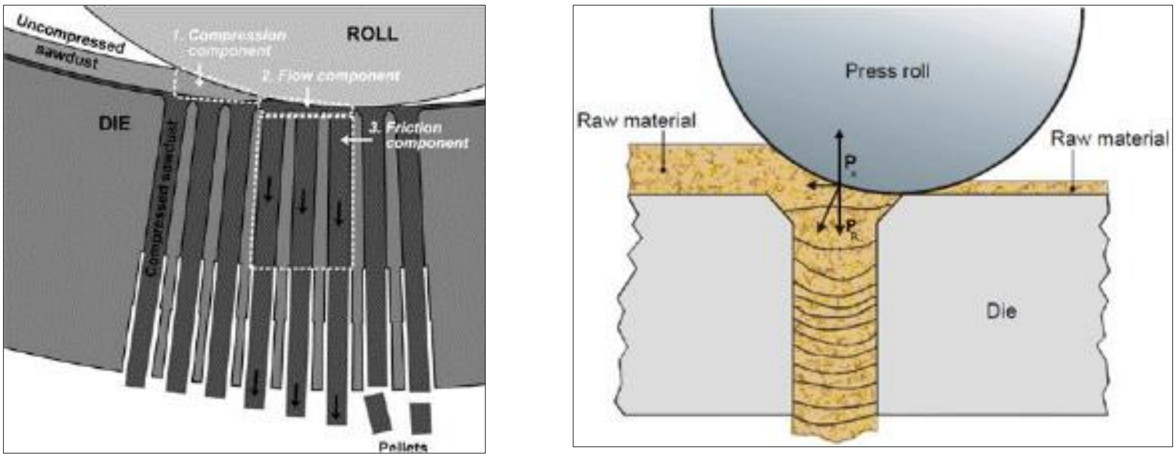
The technology is suitable for processing various types of waste, such as wood sawdust, straw, bark, feed mixtures, but also coal dust, mineral waste, fertilizers, stabilizers, or PVC waste. The technology is suitable for applications in the pharmaceutical industry and is also used in the chemical industry. The work will continue to focus on pelleting biomass. This technology is very demanding for the treatment of the input raw material before compaction. It requires dimensional adjustment of the raw material to a fine fraction, such as adjustment of the moisture content to a value in the range of a very narrow interval. The high surface to volume ratio of the pellets results in high wear of the functional parts of the pelleting machines per unit of production. Compared to briquetting technology, investment and energy consumption of pelleting is much higher. Pellets as a form of solid biofuel have one major advantage over briquettes, which outweighs all the weaknesses of this technology. This advantage and basically the only reason for the production of solid biofuels in the form of pellets is their suitability for automated combustion systems in small combustion equipment. Pellets have some properties of loose materials (Fig. 3), they can be transported pneumatically, and due to their size and shape they can be transported by screw conveyors, which predestines them for use in small combustion plants. For this purpose, they are produced from pure sawdust and shavings without the addition of any other binders (with the exception of additives of organic origin permitted by the standard up to 2% by weight). They burn with a steady and smooth flame due to their homogeneity and high energy density.

Figure 2 Pellets as pressings formed in one moment

Figure 3 Pellets from different types of wood

3. Pressing tools for pelleting machines

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 material (Fig. 4) 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 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.



a) the passage of material through the individual areas [10]

b) detail of a single channel of die

Figure 4 Biomass pelleting principle

3.1. Design of pelleting dies

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. 5) 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.

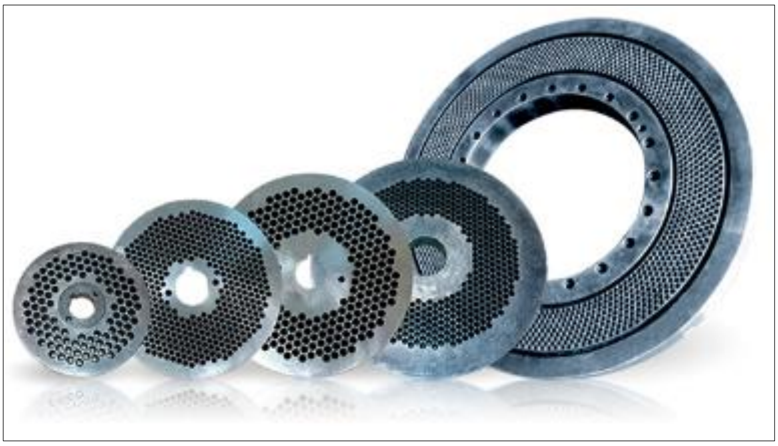


Figure 5 Design of flat pelleting die

Ring dies (Fig. 6) 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.

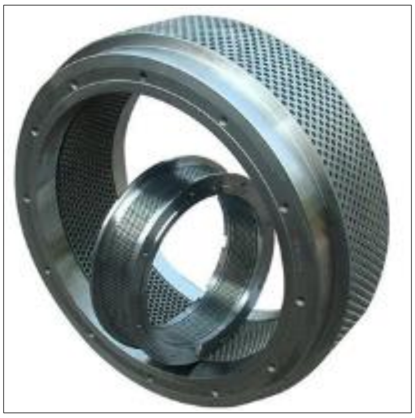


Figure 6 Design of ring pelleting die

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 (shown in Fig. 7) 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. [25] The gap between the tools is usually set to a minimum value so that a continuous pressed layer is not formed during pressing. 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 chambers of the die. The selected geometry of these chambers 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.

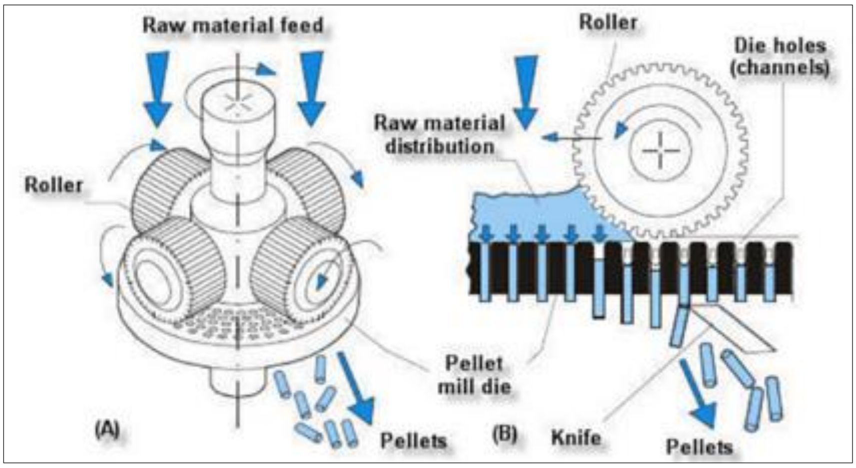


Figure 7 Operating principle of flat die pelleting machines [26]

The adjustable gap between the pressing tools - the die and the rolls - is usually set to a minimum value so that a continuous pressed layer is not formed during pressing, but to avoid excessive wear of the tools in contact with each other. However, the size of this gap is an important parameter of pelleting technology. In the case of a minimal (almost zero) gap (Fig. 8), the raw material in the form of a uniformly thick layer is pressed on the die by the action of a roll and subsequently pressed into the pressing chambers in the die. If the gap between the tools is larger (Fig. 9), the particles of the pressed raw material pass several times under the rolls before they are pressed into the pressing chambers. During this time, they go through several processes of kneading, cutting, pressing, mixing, which leads to intensive pre-compaction of the raw material. The larger fraction is reduced and the natural binders contained in the raw material are activated here, which results in a higher quality of pellets (higher mechanical resistance and hardness), but also a significant increase in energy consumption per unit of production (Fig. 10).

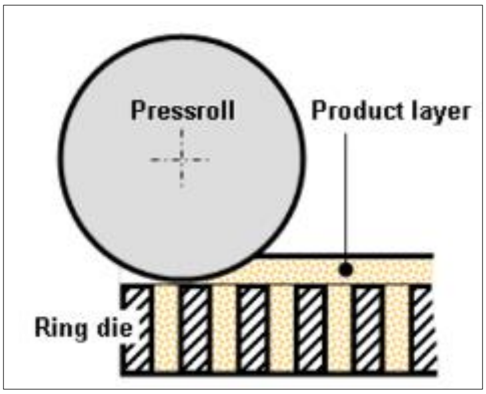


Figure 8 No roll gap between pressing tools [27]

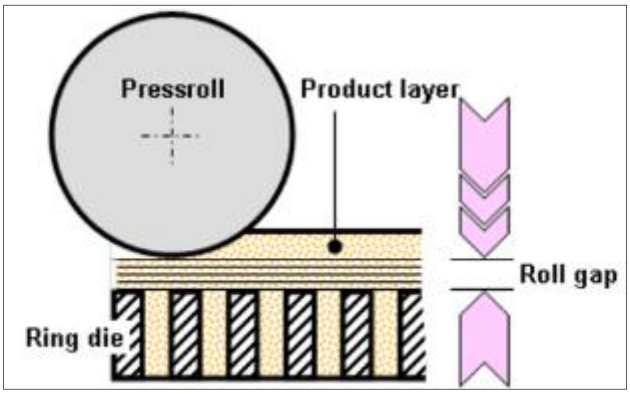


Figure 9 Some roll gap between pressing tools [27]

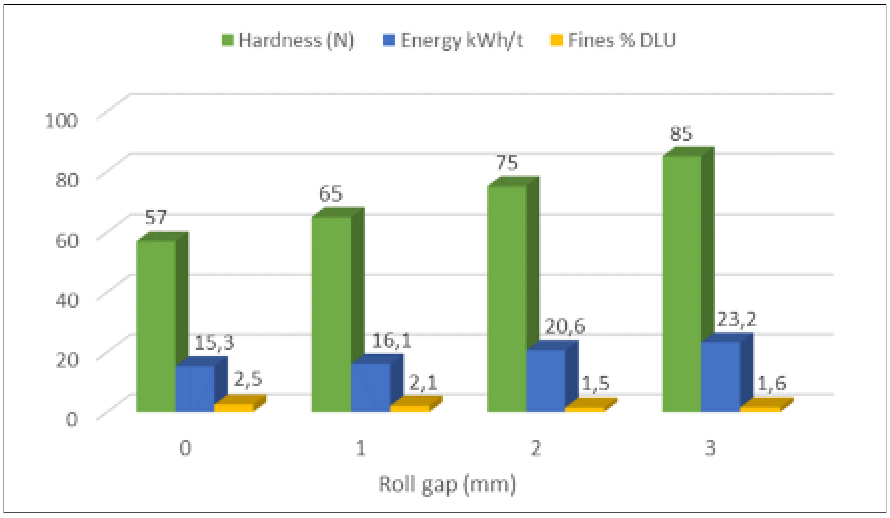


Figure 10 Effect of roll gap adjustment when pelleting feed; pellet diameter 6 mm, effective die thickness 80 mm [27]

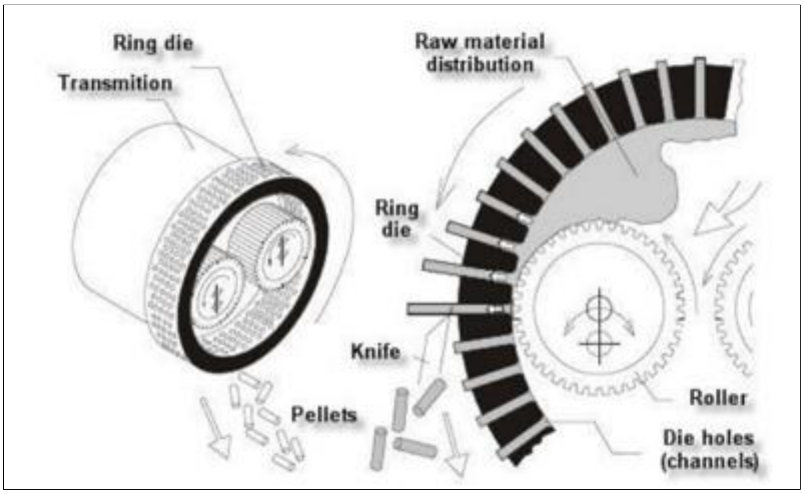


Figure 11 Operating principle of pelleting machines with ring die [26]

The principle of operation of pellet presses with a ring die (Fig. 11) 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 stirrup so, that at one revolution of the die there is a maximum of one light contact of each roll with the die. This single point contact is always present due to manufacturing deviations of the die from roundness, cylindricality, radial runout, or inaccuracy from the bearing. 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 chambers in the die to its outer surface in the form of pellets. Subsequently, the pellets of the required length are broken off with knives.

3.2. Design of pressing rolls

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. Due to the high bearing load and long operation during tool life, lubrication is ensured by either grease or forced oil lubrication, which also ensures the cooling function. The bearing space must be perfectly sealed due to the dustiness of the working environment.

Flat die pelleting presses usually have from 2 to 5 rolls evenly distributed on the die surface (Fig. 12). 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. An example of mounting and construction is shown in Fig. 13. A perfect seal of the bearing space against dust must be essential. The shape of these rolls is either cylindrical or conical.

Figure 12 Pressing rolls arrangement of flat die pelleting machine

In the case of cylindrical rolls, there is a higher and uneven wear of the surface due to the uneven circumferential speeds of the die and the roll changing in the radius of the die. This does not cause the pressing roll to roll on the die, but to slip, which leads to considerable wear when the tools are loaded with a high force.

A suitably selected apex angle of the conical rolls (Fig. 14) with respect to the diameters of the working area of the flat die ensures a perfect rolling of the roll along the die. Elimination of slippage significantly reduces the wear of the rolls and dies. Despite this fact, cylindrical rolls are mostly used for most pelleted materials, precisely because of the required slippage. Conical rolls do not slip, which can cause (and most types of difficult-to-pellet raw materials also cause) a continuous pressed layer of raw material to form on the die and stop the extrusion process. Slipping of the cylindrical rolls on the die causes entrainment and disruption of any compressed layer of raw material that may have formed. This provides greater protection against clogging of the pressing chambers and stopping the pelleting process.

In the case of pelleting machines with ring die, the number of pressing rolls is usually two to three (Fig. 15). 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. An example of a design solution for mounting a pressing roll of a pelleting machine with a ring die is shown in Figure 16, a view of the actual embodiment in Figure 17.

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 (Fig. 18), 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.

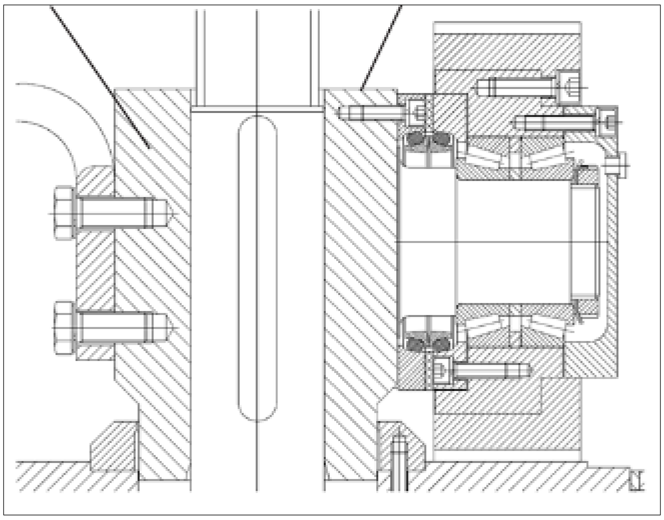


Figure 13 Bearing design solution of the roll of flat die pelleting press [25]

Figure 14 Construction of a conical pressing rolls of a flat die pelleting press

Figure 15 Pressing rolls arrangement of ring die pelleting press

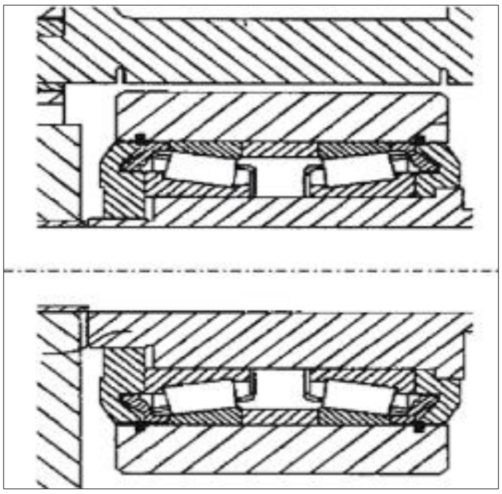


Figure 16 Bearing design solution of the roll of ring die pelleting press

Figure 17 Construction of pressing rolls of the ring die pelleting press

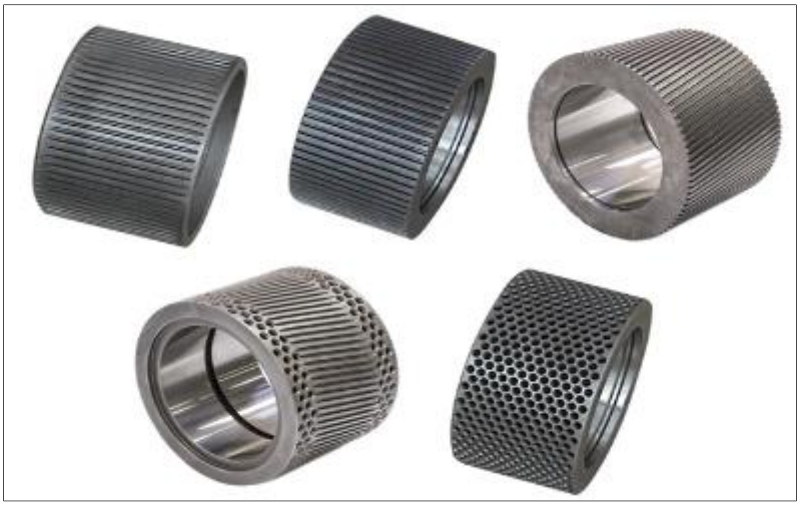


Figure 18 Used surface patterns of the outer shell of the rolls

4. Conclusion

The aim of the paper is to point out the results of research of compaction of biomass into the form of solid biofuels through pelleting technology and their evaluation in the design of pressing tools for pelletizing machines. The study examines in detail the design of pressing dies and pressing rolls. The above knowledge is based on the personal experience of the authors as designers of pelleting machines and tools. The published information is of great practical importance for the development of pelleting technology and for moving forward in the design of pressing tools.

Compliance with ethical standards

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 and the project VEGA 1/0085/19 „Research of acting forces interaction during densification of biomass and shape optimization of pressing tools of densification machines" funded by the Ministry of Education of Slovak Republic and to the Slovak Academy of Sciences.

Disclosure of conflict of interest

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

References

[1] Calderón C, Gauthier G, Jossart JM. AEBIOM Statistical Report 2017 - Key Findings.

[2] Gauthier G, et al. Bioenergy Europe Statistical Report 2020, Tech. Rep Bioenergy Europe. 2020.

[3] European Pellet Council. Pellet Statistics. 2020.

[4] Strauss W, Walker S. Global pellet market outlook in 2018, Canadian Biomass magazine. 1 Feb. 1, 2018.

[5] European Commision, A Policy Framework for Climate and Energy in the Period from 2020 to 2030, 2014.

[6] Jonsson R, Rinaldi F. The impact on global wood-product markets of increasing consumption of wood pellets within the European Union, Energy. 2017; 133: 864–878.

[7] International Organization for Standardization. ISO 17225-2:2014. Fuel Specifications and Classes-Part2: Graded Wood Pellets. Geneva: ISO; 2014.

[8] Harun NY, Afzal MT. Effect of particle size on mechanical properties of pellets made from biomass blends, Procedia Eng. 2016; 148: 93–99.

[9] Matúš M, et al. The influence of size fraction and moisture content on the compressibility of wood sawdust in effective process of production a solid biofuel. In SGEM 2014. Energy and Clean Technology: conference proceedings of the 14th International Multidisciplinary Scientific GeoConferences SGEM. Albena, Bulgaria. 2014; 553-560.

[10] Nielsen NPK, Gardner D, Poulsen T, Felby C. Importance of temperature, moisture content, and species for the conversion process of wood residues into fuel pellets, Wood Fiber Sci. 2009; 41(4): 414–425.

[11] Demirbaş A, Biomass resource facilities and biomass conversion processing for fuels and chemicals, Energy Convers. Manag. 2001; 42(11): 1357–1378.

[12] Matúš M, et al. Investigation of a mathematical-physical model for biomass densification depending on geometry of pressing chamber. In Proceedings of the international conference of the 26th European Biomass Conference: setting the course for a biobased economy. Copenhagen, Denmark. 2018; 874-881.

[13] Matúš M, et al. Mathematical models describing pressure conditions in the pressing chamber for compaction of particulate matter. Proceedings of Researchfora : international conference. Havana, Cuba. 2017; 14-19.

[14] Matúš M, et al. Pressure conditions in the pressing chamber during compaction of powder materials. International journal of mechanical and production engineering. 2018; 6(1): 13-18.

[15] Matúš M, Križan P. Influence of structural parameters in compacting process on quality of biomass pressing. Aplimat - Journal of Applied Mathematics. 2010; 3(3): 87-96.

[16] Holm JK, Henriksen UB, Hustad JE, Sørensen LH. Toward an understanding of controlling parameters in softwood and hardwood pellets production. Energy and Fuels. 2006; 20(6): 2686e2694.

[17] Kaliyan N, Morey RV. Factors affecting strength and durability of densified biomass products. Biomass and Bioenergy. 2009; 33(3): 337e359.

[18] Nielsen SK, Mandø M, Rosenørn AB. 1D model for investigation of energy consumption and wear in die designs used for biomass pelleting (Vol. 26). Copenhagen: European Biomass Conference and Exhibition. 2018.

[19] Nielsen SK, Mandø M. Experimental and numerical investigation of die designs in biomass pelleting and the effect on layer formation in pellets. In Biosystems Engineering. 2020; 198: 185-197.

[20] Mani S, Tabil LG, Sokhansanj S. An overview of compaction of biomass grinds. In Powder Handling and Processing. 2003; 15(3): 160-168.

[21] Puig-Arnavat M, Shang L, Sárossy Z, Ahrenfeldt J, Henriksen UB. From a single pellet press to a bench scale pellet mill - Pelletizing six different biomass feedstocks, Fuel Process. Technol. 2016; 142: 27–33.

[22] Serrano C, Monedero E, Lapuerta M, Portero H. Effect of moisture content, particle size and pine addition on quality parameters of barley straw pellets, Fuel Process. Technol. 2011; 92(3): 699–706.

[23] Bergman PC, Veringa HJ. Combined Torrefaction and Pelletization the TOP Process, Tech. Rep. July Energy Research Centre of the Netherlands. 2005.

[24] Nielsen SK, Mandø M, Rosenørn AB. Review of die design and process parameters in the biomass pelleting process. In Powder Technology. 2020; 364: 971-985.

[25] Kahl. Company materials and company literature of Amandus KAHL GmbH & Co. KG. Documents on design solutions of pelleting machines and tools, Reinbek, Germany. 2019.

[26] Flat die and ring die pellet mills comparision. 2021.

[27] Lessmann S. Factors that Affect Pellet Quality. Feed Milling Technology & Trends Seminar, South Africa. 2014.