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INCREASING LIFETIME of the DIE for STRAW PELLETS by CHANGING EXISTING DESIGN

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***Abstract* - Pellets can be made from practically any biomass material including straws, grasses, energy crops etc. The physical characteristics of a die can determine its performance through the blank and effective thickness, the reliefs and the hole pattern. Perhaps the most important physical characteristics of a die are the blank thickness and the effective thickness. Every opportunity should be taken to get maximum hole count in a die as it increases throughput and die life.**

In this paper will be done analysis of the existing die design for straw pellets installed in pilot plant with nominal production of 150 kg pellets/h. According to the results and pellet mill properties will be propose a new die design for increasing die life, pellet quality and decreasing operating costs.

***Keywords* - Die, Straw, Pellet, Design, Thickness**

I. INTRODUCTION

Renewable energy resources gradually attract more attention in the world. This is conditioned by two major reasons, first one is uneven distribution of the fossil fuel resources in the world and the second one is global warming phenomenon stipulates reduction of greenhouse gas emissions into the atmosphere and search for alternatives to burning of fossil fuels. Unused straw in technologies of agricultural production, as by-product of grain production, can be utilized successfully as biofuel.

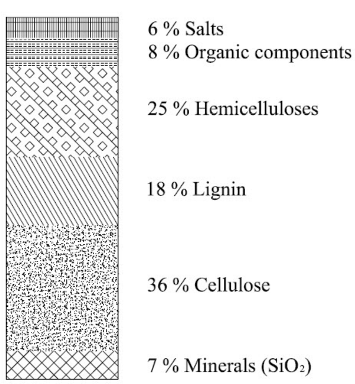

Fig. 1 Components of wheat straw

Biomass as a solid biofuel has its specific characteristics in comparison to conventional fuels, such as: chemical contents, combustion temperature, ash melting point, thermal value of the fuel and pollution degree.

Generally speaking, all biomass when taken to the level of pure fuel mass has basically the same chemical content, defined with the formula CH 1.4 O 0.6 N 0.1, but there are big differences in the polymers nature. Rijkens states that basic substances included in wheat straw's structure are: 36% celluloses, 25% hemicelluloses, 18% lignin, 8% organic components, 6% salts и 7% minerals (Fig.1)[5].

Table 1. shows the most favourable elementary chemical content of biomass. The percentage mass portion of the components refers absolutely dry matter. If we express moisture content in biomass (w) separately, then all portions should be on moist basis.

TABLE 1: ELEMENTARY CHEMICAL CONTENTS OF BIOMASS [5]

Nr.	Chemical element	Straw (%)	Spike (%)	Sunflower seed (%)	Tree (%)	Tree rind (%)
1	Carbon (C)	44,84	48,31	50,57	50,30	50,60
2	Hydrogen (H)	5,68	5,74	5,68	6,20	5,90
3	Oxygen + Nitrogen (O+N)	41,48	43,13+0,66	40,91 +0,57	43,10	40,70
4	Ash (A)	8,00	2,16	2,27	0,40	2,80

Now is important to consider that straw has higher abrasive power compared to wood, due to the presence of silica among straw's chemical components. Related to this design and material selection for the pellet mill die should be done duly to the type of the biomass.

II. PELLETING

A highly sprung roller is rotated around the inside of the heated metal plate called a "die." The die has multiple 6mm holes drilled through it of which allows the biomass to be compacted under high temperature and extreme pressure creating the carpet between the rollers and the die. This is the constantly under pressure and heat. When the conditions are correct the biomass particles pass through the die and will fuse into a solid mass this is where the natural Lignin in the straw acts as the binder turning into a straw pellets. The Blade slices the straw pellets to the required length as it passes out of the die.

Sawdust is deemed one of the best feedstock for pelleting because the lignin that is naturally present in the straw this is what binds the straw pellets together under the correct conditions[7].

Pellets are produced by compressing the straw material which has first passed through a hammer mill to provide a uniform dough-like mass. This mass is fed to a press where it is squeezed through a die having holes of the size required. The high pressure of the press causes the temperature of the straw to increase greatly, and the lignin plasticizes slightly forming a natural "glue" that holds the pellet together as it cools. The image bellow depicts the basic design and operation of the flat die pellet mill.

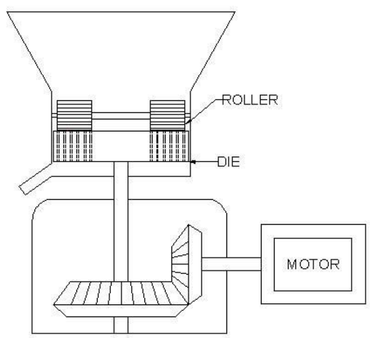

Fig. 2 Line diagram [7]

Unlike the flat die pellet mill design the ring die is positioned vertically instead of horizontally. The raw material enters the centre of the die and is compressed through the die with a series of compression rollers. Most flat die pellet mills have two compression rollers, however some flat die pellet mills have three maybe four compression rollers. The most common design of flat die pellet mill is where the die is powered and rotating, and the rollers move due to the friction and movement of the die.

Before pellet compression in the pellet mill can take place the straw, grass or any other form of biomass must be reduced in size.

III. Pilot installation pellet mill

Pellet mill LM 72 is a part of the pilot installation for producing straw pellets up to 150 kg per hour, which consists of a dosage worm/auger with a closed feeding hopper. Material for pellet mill is placed into the feeding hopper and the auger brings the material to the feed arm, where the exactly defined amount of material falls down to the mixing chamber. Nonstandard pellets and dust are returned by a spiral auger to the feeding hopper and are put through the pelletizing process again.

The pellet mill can run production from 10-150 kg/h (depends on the material) in pellet size of 3,5; 6 or 8 mm, in the standard working environment between +5 and +35 Celsius, requirements for the feed particle size 3-3.5 mm and the feed moisture level up to 12%.

The period during which this analysis of the production process was made is 3 months: November 2016, December 2016 and January 2017. A total of 8790 kg of pellets was produced. For realization of this production 31 workloads were made for eight hours, in which shifts rotated 5 operators. It was spent 8980 kg of raw material-straw, 479 kg of raw material in addition (wheat bran), 2761 kWh of electricity and 62 lit of water [4].

The largest part of production (69%) was realized in November. The price of finished pellets from waste straw in the months of production ranged from 0.107euro/kg in November, 0,132euro/kg in December and up to 0,185 euro/kg in January. If we analyse all background data and diagrams we conclude that the largest share in the cost of straw pellets from straw takes the electricity with 42-51%, then almost one third accounts for 32-33% of the labour and the rest belongs to the raw materials (straw 9-16%, additive 7-10%). The consumption of water used in the production process is negligible.

Analysed pellet mill has a flat die and two compression rollers. The common problems during pelletizing of straw pellets were pellet die blocking, overheating and bad pellet quality. During the period of analysis we try to understand what is the reason of decreasing the pellet production rate and increasing the production price. The first indicator was changes in the pellets quality, nominal output with bad quality and overheating, noticed at 203 operating hour of the line. It was done die inspection and it was noticed that we have a phenomenon called ‘’rollover’’. Rollover is the condition of the die face when the hole inlets start to peen closed. This peening action had dramatic effects on both the pellet quality and the throughput of the die, usually lowering both. Rollover is caused when the force exerted on the face of the die exceeds the toughness of the die material. Roller adjustment and raw material-straw exerted excessive stresses on the die face, initiating rollover [9].

Possible reasons were: improper handling by operators and inadequate pellet die. Due to the lack of replacement pellet die and rollers and the exigency to continue with the production process, consciously continued work, but with reduced capacity, which influenced in the increasing of the production price.

IV. Existing die and new design

Due to the fact that pelleting is a relatively new technology which is being developed every day, there are many segments in the constructive and technological process, which provide a space for further analysis, research and improvement. Logically, in the beginning analyses and research were ordered to identify the dominant constructive and technological parameters, and then to give guidelines for the functional dependence, from the position of optimal execution of the same.

The dominant technological parameters are:

- Humidity of the feeding (raw) material
- The composition of the feeding material from the position of the mixture and the percentage impact of the hardness
- The temperature of the material in the pressing zone

The dominant constructive parameters of the pellet mill die are:

- Thickness of the die (blank and effective)
- Design (angles, number and schedule of holes)
- Material

The physical characteristics of a die can determine its performance through the blank and effective thickness, the reliefs and the hole pattern. Perhaps the most important physical characteristics of a die are the blank thickness and the effective thickness. The blank thickness determines the overall strength of the die. The thicker the blank, the more it resists deflection caused by the rollers. Blank thickness should be increased instead of ligament thickness, especially in cases of repeated circumferential breakage. Effective thickness is the length of the pellet chamber that will perform the pelleting. Effective thickness governs the amount of work the die will perform on a material, increasing pellet quality. It also controls the amount of stress added to a die, more thickness is equal to more stress. Changes in material necessitate changes in effective thickness due to changes in the materials coefficient of friction. [9].

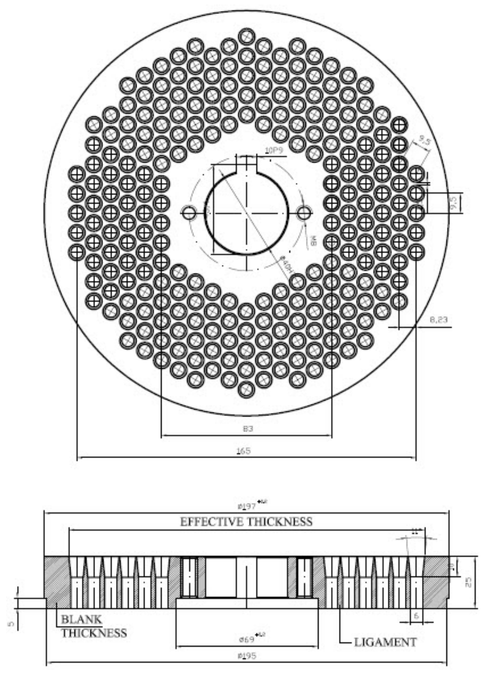

Fig. 3 Existing pellet mill die

Structure of the existing die hole provided in this paper shown on the Figure no.4 consist of tapered hole and straight hole.

The diameter of the tapered hole (d_1=8 mm) is designed to be greater than that of the straight hole (d=6 mm) to reduce the resistance of material against entering the tapered hole, and to facilitate the material to enter the straight hole. The taper of the tapered hole has a significant influence on the pelleting pressure of equipment and power consumption per ton of material, and in our case on the existing pellet mill die is $\alpha = 11^o$. Other relevant information's for existing pellet mill die are: number of die holes 260, thickness of the whole die 25 mm and measured hardness 38HRC.

Bearing in mind the existing problems in the process, analized constructively-technological parameters of the existing pellet mill die and recommendations of the other renowned manufacturers of pellet mill dies, corrections of the previous design are made in several segments:

- thickness of pellet mill die
- angle (taper) of the tapered hole (α)
- height of the straight hole (L)
- design a relief hole
- material for making pellet mill die

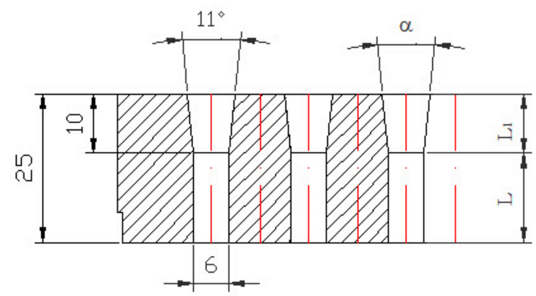

Fig. 4 Existing pellet mill die hole

Radius of the pellet mill die, die hole diameter and number of holes remained unchanged.

Proper structural design of die hole will have direct influence on the pelleting influence of the straw pellets. Due to the same types and properties of the raw material, we design, produced and analyse two different pellet mill die.

After the preparation of the technical documentation, we approached to the selection of the material and ordering production technique.

Bearing in mind that in the process of pelleting we have a working temperature in the pressing zone about 70-95 degrees we choose material X27CrMoV 51, according to EN. Material is one of the hot work chromium type tool steel. It is relatively low in carbon content and has good toughness and deep hardens by air quench from heat treatment. Good combination of toughness, hardness and wear resistance in hot. Resistance to cracking and to softening (at a temperature up to 537^{0}C while maintaining good ductility).

Production technique starts with cutting and processing on lathe machine of the defined external dimensions and thickness (nominal 30 mm, plus 1 mm for grinding). Then drilling of the cylindrical part of the die hole and formation of the entry and relief taper and making a wedge groove. After these procedures, thermal treatment (hardening) was obtained. Harden from a temperature 1000-1040 ^{0}C followed by air and oil bath quenching at 500-550 ^{0}C. Hardness of the material after quenching was 55HRC. The last operation was grinding.

Both of them has thickness of 30mm and relief hole that we provide to reduce the resistance of raw material against passing the die hole and elastic deformation of pellets.

First one has different height from the existing one (L=22 mm) and angle of the tapered hole hole ($\alpha=\beta=30^0$). In the first case increasing the height of the straight hole (L) from 15mm to 22mm we got a blackening effect on the pellet's rim, and in some cases even charred pellets and blocking the pellet die, that resulting with increased temperature in the pressing zone, delays and non-productivity.

It showed that for hard and dry raw material, like in our case, this height is huge.

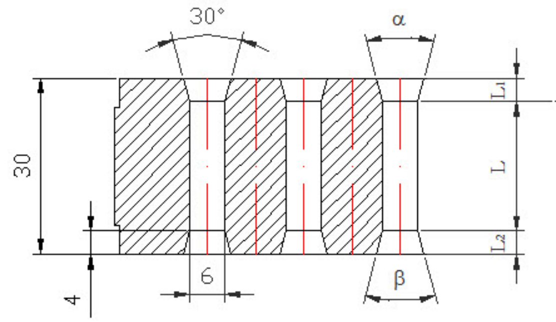

Fig. 5 First prototype of pellet mill die hole

Second one has the same height as the existing die hole (L=15mm) and angle of the tapered hole ($\alpha=\beta=16^0$).

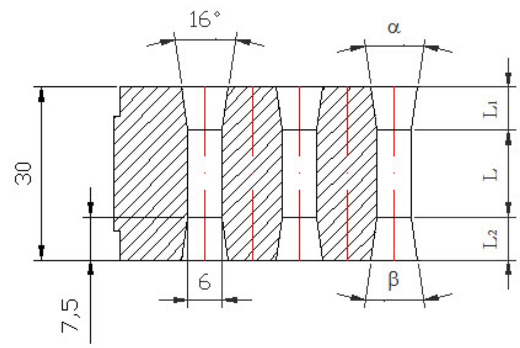

Fig. 6 Second prototype of pellet mill die hole

In this case, the height of the straight (cylindrical) hole remained unchanged, and as a result of the change in the thickness of the pellet mill die and due to the relief hole section, the input angle was reduced.

The angle of tapered hole at the entry and relief is wittingly constructed the same related to the idea of development a pellet mill die that will be double-sided. The results regarding the previous solution were visible. As a result we had a properly formed pellets through the relief tapered part, an adequate outlet from the pressing zone and the stability of the shape of the pellets.

The second one design was approved for further analysis. Additional part (Fig. 7) was designed to ensure safety fixing to the shaft and provide flat area at the upper zone. This part was made from material 42CrMo4 (alloyed carbon steel eq. to JUS Č4732).

Improper handling by operators also can be the reason of decreasing the life span and usually is related to the roller adjustment. Correct adjustment will result in maximum capacity, minimum wear on both rollers and die, and eliminate undue stresses in the pellet mill. When properly adjusted, the rollers will contact the die just enough to cause them to rotate otherwise operating the pellet mill with rolls too tight will result in peening closed the entrances to the holes in the die and excessive wear of the die and rolls. Usually we should start new dies with new rollers but taking in advance our material resources limitation we kept the old ones.

One fact that is not widely stated however is one of the most important facts in pellet production, "Only a raw material of consistent quality can produce consistent quality pellets".

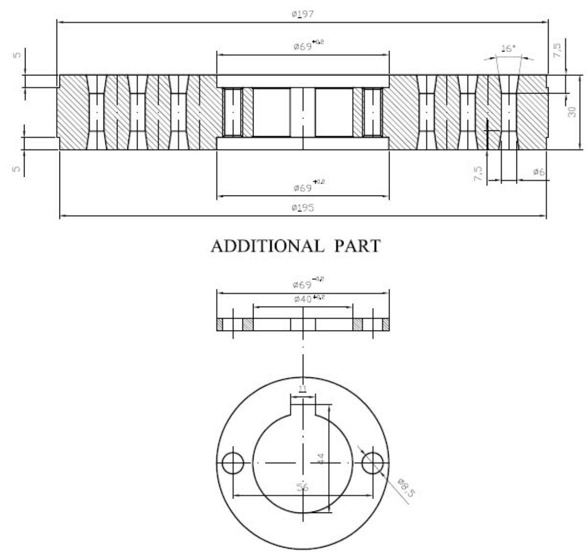

Fig. 7 Second pellet mill die and additional part

V. Conclusions

The experimental investigations were made on three pellet mill dies, an existing one that was delivered along with the pelleting line and two new pellet mill dies made according to our design.

Regarding the existing design where we have a straight relief for the newly designed we have a tapered relief. By designing the length of relief tapered hole (L_2) as well as the relief angle (β), two effects have been achieved.

From one side, an adequate output of the material from the pressing zone was assured, which kept the stability of the shape of the pellets.

From another side, the life span of the pellet mill die significantly increased, which was confirmed by the period of analysis of the newly made pellet mill die. Namely, after 256 hours worked with the new pellet mill die no problems (die face rollover, pitting/scoring or over temperature) has been observed, which we had at the existing one after 203 hours. If we take into account that after the damage on one side the pellet mill die is designed to be turned and used on the other side, it can be concluded that the life span of the newly designed pellet mill die has been minimum doubled.

At the existing pellet mill die measured hardness was 38 HRC and the material from which was made for us was unknown. The new one was made from material X27CrMoV 51 (alloyed hot work tool steel eq. to JUS Č4751) with hardness 55HRC which from the aspect of material quality is a significant factor for the extended lifespan.

It was confirmed that the length of the cylindrical part of the hole in which the pellets are formed (L) is the most influential constructive factor that directly affects the formation of pellets and the quality execution of the basic function of the system. In the first design, we had an excessive length and an effect of blackening on the pellet's rim, in some cases even charred pellets and blocking the pellet die, that resulting with increased temperature in the pressing zone, delays and non-productivity. While the secondly designed retained the length (L) of the existing pellet mill die, whereby we received pellets of good quality, normal temperature in the pressing zone and lower operating amperages, power savings. For further research the second pellet mill die was accepted.

This paper opens a field for future structural analyzes, making different pellet mill dies that will work in different conditions, examining and optimizing the straw pelleting system.

Furthermore, the constructive limiting factor is the maximum thickness of the pellet mill die (30 mm) and its radius, and the other combinations according to the number of holes, schedule, design, die material or biomass that should be pelleted exclusively depend on material assets and inputs in the preparation of different pellet mill dies and further research.

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