Design and testing functional model compacting machine for produce new shape biofuels

Ľ. Šooš1, J Bábies1, J Beniak1, Peter Krížan1, Pavel Kovač2, and Miloš Matúš1

1 The Slovak University of Technology, Faculty of Mechanical Engineering, Námestie slobody 17, Bratislava, 812 31, Slovak Republic
2 University of Novi Sad, Faculty of Technical Sciences, Trg D. Obradovica 6, 21101 Novi Sad, Serbia

* Corresponding Author: lubomir.soos@stuba.sk

Abstract Compaction technologies have been known for over 130 years. Among the best-known compaction technologies are included briquetting, pelleting and compacting. The end products of such technologies are briquettes, pellets and granules. Recent times have seen a worldwide “boom” in the use of these refinings, especially with regard to pellets. One great advantage of pellets in comparison with classic fuels is that according to need the three decisive parameters ‘shape, size and density’ of the resultant fuel can be changed during production. This leads to an optimization of costs for their production and storage and transportation requirements, but most of all, prerequisites in terms of optimal energy recovery.

One of the most discussed issues in the production of refined biofuels is the shape and size of the refined fuel. The quadrangle, n-angle or cylinder do not have optimal shapes from the point of view of automated transport in the fuel combustion process. From this standpoint the ball is the optimal shape, but it is not possible to create such pressings in a continuous process and present-day pressing and compacting machines lack a “fuel life” phase under pressure with simultaneous cooling. The endurance and cooling process has of course a great influence on the stability of the fuel produced.

The goal of the submitted paper is the development, design and testing of a new, patent-protected compacting machine construction which will allow the production of pressings biofuels of an almost circular shape. In contrast with readily available compacting – compression machines, such a compactor also provides cooling of the pressings under high pressure.

1. Defining the problems
If biofuel is to be a full-value substitute for fossil fuels, it must fulfill three basic criteria – environmental, energy and economic.

The beginning technologies for the adaption of organic waste for its later energy recovery, is its compaction under high pressure and temperature without the addition of a binder. By using these technologies, it is possible to gain refined fuel in an optimal shape and state suitable for transport, storing and later combustion. Among the best-known compaction technologies belong briquetting, pelleting and compacting, [1].

Briquetting technology is the oldest of the three. At a given time, there is usually created just one briquette. The briquettes are relatively large, (minimal characteristic dimension 30 mm) of a cylindrical, cuboid or n-angular shape. They have a smaller ratio of surface to volume and so burn more
slowly and for a longer time. They are suitable for fireplaces and hand-supplied furnaces. For larger surface to volume ratios, briquettes with larger dimensions (characteristically dimension > 80 mm) are produced with openings, [1].

With progressing automation in the combustion process, it is necessary to harmonize the factors that affect this process. Modern 21st century fuels must, in addition to the mentioned factors, also provide comfort. This is the major reason why, in recent times, the pelleting technology has been the most dynamically expanding compaction technology. The main advantage of this technology is the possibility of a fully automatic process of fuel delivery during the combustion process, even for small family furnaces. The cylindrical shape of the fuel can present certain difficulties. For problem-free feeding from the supplier to the furnace, the minimal diameter of the conveyor should be four times longer than the length of the pellet. A second factor is the wearing of the machine equipment and its parts since the rate of matrix and roller wear is given by the surface to volume ratio of the fuel. Pellets have a high ratio and also the wear rate of the contact parts of the machine and openings in the matrix is high. Combustion rate of the fuel is another factor. Pellets are characterized as having a high surface to volume ratio. Consequently the pellet surface quickly oxygenates and therefore also burns quickly, [3].

Of interest too is the technology of compaction during which a material with the required fractions and dampness is compacted between two reverse-rolling smooth or grooved cylinders are pressed against one another fig. 1. The results of compaction are granules or compressed strips that can be used for further processing, particularly in the metallurgy and chemical industries. The almost round shape of briquettes is of course suitable from the standpoint of automatic feeding, but the technology is not suitable for pressing waste from wood, because under pressure it lacks the maintaining phase. In this phase cooling of the briquette must take place, and as a result the binder, lignin, moves from the plastic to the solid state, by which the briquette acquires the required solidity, [3].

![Fig. 1 – Scheme of compacting machine. 1- feeding screw, 2- grooved bandages, 3- opposing cylinders, 4- granule](image)

A very significant factor of modern fuel is a suitable shape for automatic feeding of the fuel to the furnace.

For the already mentioned problems with automation in the process of combustion, space has been created for producing a convenient shape of fuel from the standpoint of automatic feeding. It is currently desirable to maintain the suitable shape of a briquette with a low surface to volume ratio. Such a newly-designed must also have a maintenance phase for cooling the briquette under pressure, by which the need for an additional binder, a disadvantage to compacting, is eliminated.

2. Briquette shape

The concept of an ideal briquette arose from a comparison of the properties, advantages and disadvantages of the briquettes of individual technologies. It is an attempt to create a briquette that would contain the advantages of pelleting, briquetting and compacting while at the same time eliminating the disadvantages of the individual technologies. A new briquette shape would be produced on the principle of compacting, which means being pressed between two rollers. In contrast with compacting, the new technology would have to allow for the briquette to be for a certain time under pressure, by which cooling would occur, as is common in pelleting and briquetting. Therefore, there arose the need to design a shape and, following that, a compactor machine that would manage to make new-shaped briquettes.
On the basis of the input requirements and later theoretic analysis we created the almost-round briquette, which is designed as the intersection of two half cylinders each rotated through $90^\circ$ and is suitable for automatic feeding. With such a briquette it is possible to regulate the ratio of the surface to its volume. The edges at the intersection of the two cylinders allow optimal lighting of the briquette, [4].

3. Kinematic
After the design of a suitable shape for the briquette, we continued with a combination of potential solutions and to the design of a kinematic compactor that would be capable of producing such briquettes. The result of this combination was a proposal for a completely new principle “Ring compaction machine“. In 2010 we received a granted patent SK 287505 B6, [2] for the stated principle. The invention belongs to the area of compaction of bulk organic and inorganic materials.

The essence of the new patented solution is large ring 1 which has in its interior circumference a great number of slots 3 in semi-cylindrical shape whose axes are parallel with the axis of rotation of the ring. The compression instrument is also disc 4, which on its outside circumference has a cylinder slot 5, which fits into the slots of ring 1 and is turned $90^\circ$ from the slots of the ring. So both the ring and the compression disc have independent movement. The hold-off stage under the pressure at which the molds are cooled is ensured by the calibration struts 6. In stage A there takes place the filling of the press chambers that appear during rotation, in stage B compression, in stage C partial expansion and finally in stage D gradual cooling of the briquette under pressure, and its calibration. The effect of curing of the binder brings the binder (lignin) from the plastic to the firm state, by which the briquette achieves the required rigidity, [2].

4. Design and production of functional model
A further task arising out of the work on the overall project was designing the compacting machine itself. At the beginning, an analysis of kinematics of motions and the combination of possible structural solutions was carried out. In order to achieve the required briquette shape and kinematics of motions we designed a functional model of the compacting machine as shown in figure 4.
Design of force elements was based on a theoretical analysis of the forces calculated during the densification process. On the basis of such forces, calculations were made for the required input of the main drive, input of the drive of the compacting disc and the drive of the feeding screw.

Another very important task related to designing the functional model was testing of strength and shaft sag of the compacting disc, as shown in figure 5 and the overall solidity of the frame, figure 6. In figure 5 we can see the area of the maximum shaft sag indicated in red. This is the area directly under the compacting disc. The maximum shaft sag is 0.303 mm in the direction of the loading force. In figure 6 the largest deformation of the frame in a direction of pressing force can be clearly seen. The largest shift is displayed in the upper part of the frame, 0.566 mm.

The final task in this part of the project was to prepare the manufacturing sketches and the final manufacture of the functional model, figure 7.

5. Testing of functional model

In this part of the task two basic types of testing were performed on the functional model. The objective of the first set of measurements was to determine the required density of a briquette on the functional model. The second very important task in this experiment was to determine the maximum pressing force for the set density of the briquette.

5.1 Setting of briquette density

The foundation of this testing was to determine the required volume of the briquette $V \ [m^3]$ and the assumed theoretical density of the briquette $\rho \ [kg \cdot m^{-3}]$. With a calculated volume of the briquette $V=1.531 \times 10^{-6} \ m^3$ and a set theoretical value of density $\rho=1,000 \ kg \cdot m^{-3}$ the weight of one briquette will be $m=1.531 \times 10^3 \ kg$. For those values we subsequently pre-set the frequencies of revolution of the feeding screw while maintaining the revolutions of ring and compacting discs at a constant level. Subsequently,
we conducted 3 sets of measurements, while gradually raising the revolutions of the feeding screw. For each measurement, 10 random briquettes were selected and measured, as shown in Table 1.

5.2 Determination of pressing force
First of all, it was necessary to calibrate the strain gauge. We loaded the shaft under the compacting disc of the hydraulic compactor DHL 15, made a reading of the measured force from the IMADA dynamometer and subsequently, we allocated the respective tension to the value of the force, figure 9. We repeated the process of calibration four times and subsequently made an average of the values; all the measured values can be seen in the figure below.

Following the measurement, we moved the calibration curve through the average dependency, as can be seen in figure 10. We mounted the calibrated shaft onto the device and began the process of compacting sawdust. The courses of tension were recorded by means of an Omega ON-DAQXL device.

![Figure 7 The actual structure of a ring compacting machine](image1.png)

![Figure 8 The quality of briquettes at various feeding screw revolutions](image2.png)
Table 1 Weight of briquettes

| Weighted briquette | Weight (g) n=30 min⁻¹ | Weight (g) n=35 min⁻¹ | Weight (g) n=40 min⁻¹ |
|--------------------|------------------------|------------------------|------------------------|
| 1                  | 1.164                  | 1.341                  | 1.356                  |
| 2                  | 1.247                  | 1.389                  | 1.192                  |
| 3                  | 1.371                  | 1.251                  | 1.346                  |
| 4                  | 1.276                  | 1.319                  | 1.375                  |
| 5                  | 1.352                  | 1.295                  | 1.346                  |
| 6                  | 1.194                  | 1.249                  | 1.356                  |
| 7                  | 1.293                  | 1.372                  | 1.381                  |
| 8                  | 1.316                  | 1.298                  | 1.329                  |
| 9                  | 1.24                  | 1.382                  | 1.382                  |
| 10                 | 1.42                  | 1.146                  | 1.361                  |
| Average weight     | 1.2873                 | 1.3042                 | 1.3424                 |

Each measurement provided the output in the form of a text file, including the respective values that were then processed in Excel, thus identifying the maximum measured value. In the third measurement, we achieved a maximum tension of 1.95 V at a briquette density of $\rho = 876.51 \text{ [kg.m}^{-3}\text{]}$, Figure 11. This value was inserted into the equation of the trend line of the calibration diagram. By inserting the values in the equation $y=60.241x-2.3084 \text{ [kN]}$ the final values of the maximum pressing force were achieved, Table 2.

Figure 9 Dependence of loading force on strain gauge tension

Figure 10 Average dependence of loading force
6. Discussion and Conclusion

The goal of the presented paper is the design and function testing of a new progressive conception of a compaction machine for the production of a new optimised shape for refined biofuels. In their design for a new briquette shape and the design of a machine for their manufacture, the authors started out from a wide-ranging analysis of the advantages and disadvantages of known compacting technologies. For the new shape we created a principally new kinematic compacting press, designed and made a functioning model for testing the principle and attempted the production of new briquette shapes. There is still a lot of work to be done to optimise and perfect the construction. It will be necessary to perform a number of verification calculations and measurements, synchronize the rotation speed of the filling screw with the speed of the ring and press disc in order to get the optimized amount of raw material into the press chamber, and therefore the optimal briquette density. Work still has to be done on the easy removal of the briquettes from the ring as well as on the device’s performance when managing several rings next to each other. The first experimental and function tests have already shown the justification of the new construction and the correctness of the path taken.

Acknowledgements

The research presented in this paper is an outcome of project No. APVV-16-0476 “Research and development of the progressive design of the high speed rotor mounting in spinning machines” funded by the Slovak Research and Development Agency.

References

[1] L. Šooš, S. Korgo, The Effect of Wood Humidity on Briquet Quality, 5th Conference on Environment and Mineral Processing (part. 2), pp. 577-583, 2002
[2] L. Šooš, Kontinuálny spôsob lisovania biomasy do optimálnych výliskov a zhutňovací stroj, Patent number: SK 287505. – Date of acquisition: 14. 10. 2010
[3] Šooš, L. - Matoš, M. - Beniáč, J. - Križan, P.: Development of the compaction machine for the production of new shapes of pressed biofuels. In: 8th TMSE ICOME 2017, 297 (1/2018) doi:10.1088/1757-899X/297/1/012008.
[4] Blaško, P.: Progressive construction of an annular pellet machine, Diplom project, STU Bratislava, 2018, 58 p.