# OPTIMIZING EQUIPMENT AND TECHNOLOGICAL PROCESSES FOR CUTTING AND SHREDDING BIOMASS FOR PELLET AND BRIQUETTE MANUFACTURING

**PhD thesis – Abstract**

For obtaining the scientific title of PhD with the
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## INTRODUCTION

Biomass plays a significant role in the transition to green and renewable energy sources and in the reduction of pollutant emissions. Pellets and briquettes obtained through the chopping, grinding, and pressing of biomass, using pelletizing/briquetting processes, are efficient and eco-friendly energy sources with utility both in households for heating buildings and in industrial processes.

The manufacturing process of pellets and briquettes involves pressing the chopped and ground raw materials at a specific temperature for subsequent use or further processing. (Bridgwater, 2006)

Cutting and grinding the biomass for pelletization/briquetting represent the initial transformation stage of biomass into a suitable form for the continuation of the production process. Proper cutting and grinding of biomass can increase energy efficiency and reduce greenhouse gases compared to burning it in its raw form. (Beniak, 2012) The correct selection of cutting and grinding equipment is vital for the smooth operation of the production process.

### Importance and necessity of the topic

The chosen topic is a current and highly important one for energy progress, especially in the current context where armed conflicts and the effects of the pandemic have had an impact on energy prices, particularly non-renewable sources of energy. Energy is an essential component of the progress of civilization, especially technological progress, as every activity or technological process requires a considerable input of energy to function. Considering the rapid development of technologies, population growth, and the awareness that some energy sources are finite, the search for new sources of energy and new methods of producing it has begun, even using waste from other sectors such as agriculture, forestry, or furniture production.

### Objectives of the research

The primary objectives of the doctoral research, which are reflected in the thesis, are:

PO1 Optimization of equipment and technological processes for cutting and grinding biomass for the production of pellets and briquettes;

PO2 Optimization of production by improving manufacturing recipes for pellets and briquettes through planning and scientific industrial research.

The secondary objectives are:

SO1 Designing experimental activities by developing a methodology for experimental research;
SO2 Proposing optimizations for production line subassemblies;
SO3 Proposing optimizations within the production process;
SO4 Proposing optimizations for production digitalization.

**Structure of the thesis**

The proposed thesis is structured into 7 chapters, starting with an introduction that presents the research topic and its importance in the context of the 21st century.

Chapter 1 provides a current context of the topic and establishes a reference framework, considering the most recent knowledge.

In Chapter 2, the possibilities for optimizing the manufacturing process to produce feed pellets and heating briquettes are explored, with a focus on factories in Cenei, Timiș County, which aim to expand through accessing non-refundable funds for the acquisition and optimization of production lines.

Chapter 3 contributes to the optimization of manufacturing lines by introducing innovative subassemblies and the use of modern technologies.

Chapter 4 focuses on experimental research that evaluates the quality of products, the performance of the grinder, and the calorific value of the biofuel obtained from mixtures.

In Chapter 5, optimized recipes for pellet production from mixtures are developed, including research methodology and the selection of optimal recipes.

Chapter 6 explores the possibility of using artificial intelligence in pellet and briquette production, including classification neural networks and adaptive neural networks.

Chapter 7 contains general conclusions, highlighting the author's personal contributions and suggesting future research perspectives. Throughout the process, the thesis has a clear goal of optimizing the production of pellets and briquettes, addressing both theoretical and experimental aspects, as well as the possibilities brought by artificial intelligence.

# 1 CURRENT STATUS OF THE THEME TOPIC

The current status of the thesis topic represents the solid foundation upon which the entire research is built. Given the complexity of the subject, it has been deemed essential to present the current status from various key perspectives, thereby providing a comprehensive background for the research work.

First and foremost, the current status and trends in the production of pellets and briquettes for heating are examined. This aspect is crucial as it provides a profound understanding of market requirements and needs, as well as the evolution of technologies in this field. Industry changes, both in terms of materials used and production processes, are essential for optimizing production lines.

Another important aspect is the status and trends in the field of cutting and grinding equipment used in pellet and briquette production. Technological advancements in this sector can bring significant improvements in production process efficiency, reducing costs, and environmental impact.

Furthermore, the status and trends in the digitization of the design and operation of pellet and briquette production lines are explored. This includes concepts such as "Cloud manufacturing," "Cyber manufacturing," "Reverse engineering," and "Industry 4.0." These revolutionary approaches can enhance the efficiency of biofuel manufacturing by connecting devices and processes to the internet and using real-time data analysis for production optimization.

By addressing these multiple perspectives on the status of the thesis topic, the research is built on solid and up-to-date foundations, setting the stage for further development of solutions and innovations in pellet and briquette production, with a particular focus on efficiency and sustainability in the contemporary era.

**Current Status and Trends in Pellet and Briquette Production for Heating:**

This represents an assessment of the current situation in the production of pellets and briquettes used as biofuels for heating. It includes the analysis of the materials used, market demand for pellets and briquettes, as well as current production technologies. Trends may encompass changes in the materials used, increased production efficiency, improvements in grinding and pressing processes, or the development of alternative biofuels.

Progress in this industry has been driven by quality standards imposed by the European Union. These standards are continuously updated based on research findings aimed at creating a renewable, sustainable energy resource.

The main EU regulations regarding solid biofuels are found in the standards:

EN ISO 17225-1;
EN 17225-2;
EN 17225-6 (CEN (European Committee for Standardization), May 2014).

**The current status and trends in the field of cutting and grinding equipment used in the production of pellets and briquettes:**

It refers to the assessment of the machinery and equipment used to cut and grind the materials required for the production of pellets and briquettes. It involves the analysis of current cutting and grinding technologies, their efficiency, as well as trends in the development of more advanced or energy-efficient machinery to optimize the production process.

**The current status and trends in the digitization of the design and operation of pellet and briquette production lines:**

This aspect refers to the introduction of digital technologies into the design and operation of production lines for pellets and briquettes.

Subcategories include:

Cloud manufacturing: This involves using cloud infrastructure to store and access production-related data, enabling more efficient collaboration and monitoring of production processes.

Cyber manufacturing: This concept involves connecting devices and processes to the internet, allowing remote monitoring and control, and using real-time data analysis for production optimization (Lee, 2016).

Reverse engineering: This refers to the process of disassembling and analyzing an existing product or machine to understand and reproduce its design or functionality, which can lead to improvements or optimizations in production.

Industry 4.0: This is a paradigm of the industrial revolution that involves integrating advanced technologies such as the Internet of Things (IoT), artificial intelligence, and advanced automation into production processes (Sommer, 2015).

# 2 POSSIBILITIES FOR OPTIMIZING THE ARCHITECTURES OF PELLET AND BRIQUETTE PRODUCTION LINES

This chapter of the thesis aims to analyze the architectures of the production lines of the two factories in Cenei and propose optimized architectures that meet the needs expressed by pellet and briquette manufacturers.

The main results presented in this chapter are:

An optimized production line for feed pellets.

An optimized production line for pellets and briquettes used for heating.

Both production lines discussed in this chapter have many similar subassemblies, although the form of the equipment may vary. However, the purpose is the same, with differences being determined by the design approach. An essential element in the pellet and briquette manufacturing process is the grinder.

Both production lines are equipped with straw grinders from different manufacturers, with different constructions. However, a significant difference between the two lines is the presence of the branch grinder, which belongs to the heating pellet production line.

Optimizing a specific architecture to produce heating pellets and briquettes involves considering multiple aspects and approaches to maximize production efficiency and quality.

Regarding the optimization of the production line architectures for feed pellet production, various aspects can be analysed, such as the efficiency and quality of the obtained products. For example, one can evaluate how raw materials are brought in and processed in the line, the level of automation of processes, and the interconnectivity between subassemblies. This allows proposing modifications to reduce material losses, increase production, and ensure better quality control.

As for optimizing the architectures of production lines for heating pellet and briquette production, one can analyse the efficiency of grinding and pressing processes, efficient energy use, and the implementation of real-time monitoring and control technologies. Optimization proposals may target increased energy efficiency, reduced production time, and improved quality of the final products.

Furthermore, optimization proposals for the pellet-briquette production line architectures have been developed using elements of graph theory (Deo, 2017). The use of graph theory can provide a useful perspective on how elements and subassemblies in the production line are interconnected and how these connections can be optimized to achieve desired objectives. This involves analysing the process network and material flow to identify potential optimization points and element proximities (Evans, 2017).

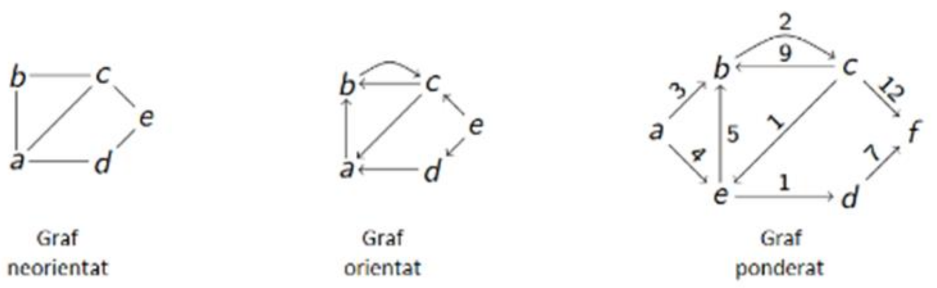


**Figure 2.1 Examples of Graphs**

# 3 CONTRIBUTIONS TO THE OPTIMIZATION PROCESS OF PELLET AND BRIQUETTE PRODUCTION LINES

This chapter has as its main objectives the identification of ways to innovate subassemblies in the production line and the presentation of an improved version of the straw bale shredder. The results of this chapter include the presentation of optimization solutions and an enhanced version of the straw bale shredder.

To achieve these objectives, we began by evaluating the condition of the equipment used in the production line. This revealed that most of the equipment was purchased between 2017 and 2022, with special attention to ensuring compatibility by purchasing from the Eco Mihiș manufacturer. However, equipment from other companies, such as the branch shredder and the briquette press for parallelepiped briquettes, was also acquired. The evaluation showed that many of these pieces of equipment and subassemblies had suffered wear and tear due to usage and technological advancements.

To improve the efficiency of the production line, we explored ways to innovate existing subassemblies. This involves reviewing and modernizing equipment and processes to make them more efficient and reduce losses. By identifying weaknesses and optimization needs, we proposed concrete solutions for each subassembly or piece of equipment.

We also analyzed and applied modern technologies in the manufacturing of innovative subassemblies in an attempt to bring about significant improvements.

An important aspect of production line optimization is the straw bale shredder. We identified structural solutions to improve its performance, reducing wear and material losses. By modernizing and innovating this subassembly, a significant increase in the efficiency of the manufacturing process can be achieved.

**Figure 3.1 Cutting Assembly Detail**

# 4 EXPERIMENTAL RESEARCH ON THE QUALITY OF PRODUCTS PRODUCED ON OPTIMIZED PRODUCTION LINES

This chapter has as its main objectives the attainment of results that establish the properties of the shredded material depending on the motor speed of the cutting equipment and the production of heating pellets from various biomass mixtures using the optimized production line. The results of this chapter include data regarding the performance of the shredder, the assessment of the calorific value of the obtained biofuel, and the analysis of the properties of the pellets obtained from biomass mixtures.

**Methodology for Experimental Research on the Shredder's Performance:**

To evaluate the performance of the shredder, a rigorous experimental methodology was followed. The raw materials used were barley straw, alfalfa, and hay from meadows.

The experiment stages included:

• Starting the shredder without load and measuring parameters such as motor temperature, RPM (revolutions per minute), vibration speed, and amperage/consumption.
• Adding the bale to the shredder.
• Adjusting the motor RPM to different values, such as 500, 1000, 1500, and 1800 RPM.
• Starting the shredder and monitoring it for 5 minutes.
• Recording the RPM during operation, vibration speed, and amperage/consumption.
• Stopping the shredder.
• Determining the moisture content of the shredded raw material.
• Collecting two 1-liter samples of the shredded raw material.

These steps were repeated for each RPM and each type of raw material. This experimental process allowed for the collection of relevant data regarding the shredder's performance and the influence of motor RPM on it.

**Performance Assessment of the Shredder:**

Several tests were conducted under real conditions using different types of straw and varying electric motor speeds. During the tests, electric motor vibrations were continuously measured, and infrared scanning was performed. This shredder performance evaluation process provided essential data for understanding how it operates and how it can be optimized to reduce production costs.

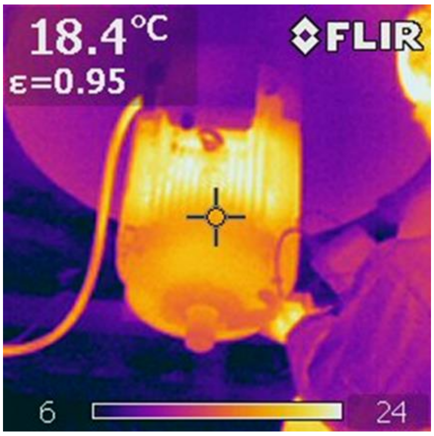


**Figure 4.1 Thermal scan (IR 1)**

**Figure 4.2 Measuring device**

**Methodology for Experimental Research on the Calorific Value of Biofuel Obtained from Mixtures:**

To evaluate the calorific value of biofuel obtained from biomass mixtures, a research methodology was developed. This involved selecting the expected responses and relevant experimental factors, such as motor RPM and the composition of biomass mixtures. An appropriate experimental plan was developed to obtain meaningful data, and a mathematical model was used to analyse the results.

**Measurements and Results Regarding the Performance of Regular Biofuel:**

For the three selected recipes chosen for analysis, samples of pellets were prepared, and their properties were analysed in the UPT laboratories. These analyses included assessing the calorific value, moisture content, and other important characteristics of the biofuel. The obtained results allowed for the evaluation of pellet quality and provided essential data for determining the efficiency of the biofuel obtained from biomass mixtures.

# 5 OBTAINING OPTIMIZED PELLET RECIPES FROM MIXTURES USING SPECIFIC METHODS

The main objectives of this chapter are:

• Determining optimal recipes for pellets from biomass mixtures based on field trials conducted and presented in Chapter 4.
• Selecting optimal recipes for mass production.

These objectives have significant implications for the efficiency and quality of pellet and briquette production and represent a crucial step in the optimization process of production lines.

Research Methodology:

To ensure that the research and results obtained are in line with international standards, specific regulations and standards for the biomass fuel production industry were considered. These standards provide guidance on the quality of raw materials, specifications for finished products, and testing procedures. Using these standards ensures that the obtained recipes comply with industry requirements.

Processing Experimental Data:

To develop optimal recipes, experimental data obtained in the research presented in Chapter 4 were processed. This process included data analysis, identifying relationships between relevant variables, and developing regression equations to model process performance. Two specific methods were used:

Optimization with Statgraphics:

Statgraphics software (Mariș, 2022) was used to develop regression equations to assess and optimize the production process of pellets from biomass mixtures. This allowed for the identification of the influence of various factors on pellet quality and the development of models to predict results based on input variables.

Optimization with Maple:

Maple software was used to obtain optimized values for production parameters and pellet recipes. Advanced mathematical algorithms were used to identify the optimal combinations of raw materials, RPM, and other production factors to produce the highest-quality pellets.

Selection of Optimal Recipes:

Based on processed data and result analysis, optimal recipes for pellet production from biomass mixtures were chosen (Nilsson). These recipes include detailed specifications regarding the proportions of raw materials, production parameters, and other necessary details to produce high-quality pellets efficiently and sustainably. The selection of these recipes was guided by the objective of maximizing production quality and efficiency while ensuring compliance with international standards and market requirements.

The main conclusions of this chapter are:

- Economic efficiency is inversely related to efficiency in terms of residual ash production.
- Recipes can consist of one or more components in different percentages, including additives, if necessary, although mixtures containing additives were not created within the thesis.
- Recipes can be optimal even if they do not include raw materials shredded with the analysed shredder.

# 6 POSSIBILITY OF USING ARTIFICIAL INTELLIGENCE TO SUPPORT PELLET-BRIQUETTE PRODUCTION

Chapter's main objectives include the use of artificial neural networks to assess the performance of proposed solutions and determine the ideal type of raw material, whether wood-based or non-wood-based, based on the quantity of emitted pollutants. The results of this chapter involve the development of a neural network for raw material classification and neural networks for determining fuel material properties.

**Theoretical Foundations of Artificial Intelligence:**

In this chapter, we presented the theoretical foundation of artificial intelligence, with a focus on artificial neural networks (ANNs). We explored the basic concepts, the structure of an ANN, and how they can be trained to perform specific tasks such as classification or prediction.

**Determining the Type of Raw Material (Wood-based or Non-wood-based) Based on Emissions:**

The objective was to develop a neural network capable of classifying the type of raw material used in the production of pellets and briquettes, considering the level of emissions. This would enable the selection of optimal raw materials for biofuel production, taking into account environmental impact and energy efficiency.

The neural networks developed with Statgraphics can be used for raw material classification.

The database used for constructing the neural networks with Statgraphics has the following structure:

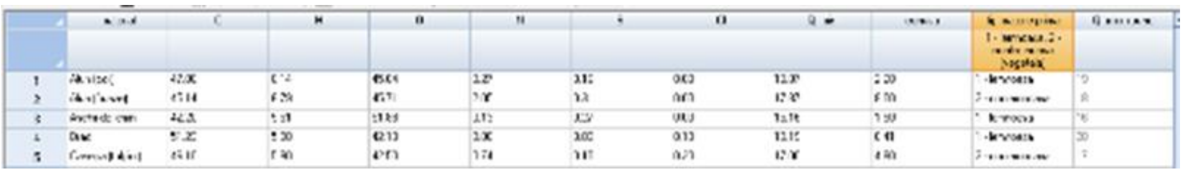

**Figure 6.1 Database structure**

And contains 76 entries. For each of these entries, the elemental composition, calorific value, residual ash, a rounded calorific value, and classification of the entry as either woody biomass or non-woody biomass were recorded.

**Determining properties using ANNs in production assistance (Matlab):**

I used artificial neural networks (ANNs) to determine the properties of the fuel material. These properties include calorific value (Maris, Nenu, Maris, & Slavici, 2017), moisture content, and other relevant characteristics. Using ANNs for this purpose helps optimize the production process and ensure consistent quality of pellets and briquettes.

The process of creating an artificial neural network involves several distinct phases, including initializing the network's parameters, establishing connections between layers, and ultimately training the network.

# 7 CONCLUSIONS. PERSONAL CONTRIBUTIONS. RESEARCH PERSPECTIVES

**Main Conclusions:**

One of the main conclusions of the thesis is that there are significant opportunities to optimize the subassemblies of a pellet and briquette production line, especially cutting assemblies. This research has demonstrated that it is possible to develop hybrid machines that can cut and grind simultaneously, thereby reducing the number of required subassemblies and energy consumption in the production process.

Additionally, there are several ways to optimize the entire production line, and these methods have been presented, developed, and even implemented in the pellet production factories in Cenei. Using graph theory to propose optimization solutions has significantly reduced the number of trials required to obtain valid results.

Simulation processes were essential in production optimization, reducing costs and the time needed to implement optimizations.

**Personal Contributions:**

Theoretical contributions of this thesis include the development of optimization proposals based on graph theory, the creation of an artificial neural network, and optimization proposals for networks using artificial intelligence.

At the experimental level, personal contributions include testing the second version of the straw chopper in a machinery factory in Bihor County, making modifications to the production line according to graph theory, optimization proposals for networks using artificial intelligence, and the development, testing, and verification of various heating pellet recipes in the Cenei factories and UPT laboratories.

**Further Development Perspectives:**

Considering the experience gained during the research for this thesis, as well as working as a researcher on the implementation of EU-funded projects, it can be considered that these results can serve as a basis for further funding requests. Such funds could support the development of research in new and interesting directions.

Other identified directions for further development include:

- Continuous optimization of production lines through the acquisition of more modern equipment.
- Optimization of equipment to reduce energy consumption and increase productivity.
- Development of pellet recipes adapted to the needs of pets.

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