IOSUD - Universitatea Politehnica Timişoara
Şcoala Doctorală de Studii Inginereşti

CONTRIBUTIONS TO THE OPTIMIZATION OF THE MANUFACTURING PROCESS OF PELLETS/ BRIQUETTES AND THE ARCHITECTURE OF THE HEATING PLANT FOR THEIR COMBUSTION

PhD thesis – Abstract

to obtain the scientific title of doctor at
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in the field of Industrial Engineering PhD

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The thesis is structured in 7 chapters and 10 annexes. The first 2 chapters being introductory and support chapters in which the thesis is motivated, the current state of the research in the field is analyzed and the necessary notions are introduced to address the thesis theme. The following chapters describe the research activity carried out to optimize the technological process of pellet and the realization of a pilot heating plant with pellet operation. The last chapter is reserved for conclusions and presentation of personal contributions.

1. INTRODUCTION

In this paper, the achievements regarding the optimization of the technological process of pellet, respectively the pilot heating plant for their combustion will be presented. The following will be detailed the importance and necessity of the chosen theme, the objectives of the research and the structure of the work.

The importance and necessity of the chosen theme

Lately, we are seeing that sustained efforts are being made in the field of energy to solve the transition to renewable systems for the production of RES energy, in the conditions of sustainable energy development. It is intended to provide the population with the necessary energy needs without consequences of a major change in the planet's ecosystem. The present work approaches a topical topic in the field of energy production from renewable energy sources (RES) with the assessment of the energy potential of biomass, by burning it in high-performance, low-cost thermal power plants. Since ancient times, biomass has played an important role in the energy economy of the planet and, although in 1870 its place was taken by fossil fuels, nowadays it has become again one of the main sources of renewable energy. The research topic was chosen taking into account:

a) the current global needs and problems in the field of energy.
b) the untapped biomass potential of Romania.

Regarding the current needs and problems at global level in the field of energy, this paper proposes the introduction of a heating system with a heating plant on woody biomass that can improve performance, consumption, autonomy and decrease the degree of pollution, thus contributing to the achievement of the goal proposed by the European Green Deal with its specific objective, OP2–(ii) Promotion of energy from renewable sources in accordance with Directive (EU) 2018/2002.
Regarding the untapped biomass potential, we can say that Romania has a biomass potential valued at over 7500 thousand tons of oil equivalent / year, and its exploitation could cover approximately 70% of Romania's commitments regarding the contribution of renewable sources in the total energy consumed. The paper proposes an optimal solution for a technological line for the production of pellets / biomass briquettes to increase productivity, diversify the raw material and ensure an optimal working environment. At the same time, a technical solution is proposed for the supply of a steam boiler with solid biomass (mixed with coal).

Research objectives

Optimizing the manufacturing process of pellets and briquettes for heating can refer to maximizing profit, increasing productivity, recycling waste of agricultural or forestry origin, maximizing calorific power, determining new manufacturing recipes, innovative solutions for automating the production line, etc. The optimization of the pellet manufacturing line and the realization of a line for preparing and supplying biomass to a boiler on steam is the first objective of the research.

The construction of a pilot biomass combustion plant that can improve performance, consumption, autonomy and pollution, with a low cost and a possibility of widespread use, especially in rural areas that can be automated and included among smart-home devices, is another major objective of the research.

The primary objectives set during the doctoral research stage are:
PO1 obtaining scientific results regarding the renewable natural resources in Romania in order to use them in the process of pellet, respectively of burning
PO2 building a reliable and affordable pilot plant for private homes

In order to achieve the primary objectives, it is necessary to achieve in advance the following **secondary objectives**, corresponding to the activities carried out during this research period:
SO1 design of experimental activities and development of the methodology for carrying out experimental researches
SO2 proposal to optimize the manufacturing process of pellets/ briquettes on an existing technological line
SO3 design of a pilot heating plant
SO4 documentation for the patent application related to the pilot plant

Structure of the work

The thesis is structured on 7 chapters. In order to achieve the first objective, we start from the presentation of the technological process on a pellet / lighter manufacturing line existing in a profile enterprise, then solutions are identified for its refurbishment and for the innovation of the two production lines, and after commissioning, experimental tests are made to study its optimal functioning. On the optimized manufacturing line, pellets are made and are then burned in the pilot heating plant.

New directions of research and diversification of production are identified, as well as premises for the development of the company.

From the study of specialized bibliographers was made a database with raw materials that can be pelleted, the database being completed with new materials for which the experimental determinations were made.

To achieve goal two, it starts from two major inventions (the steam generator and the rocket stove), a technical solution is identified for the design and realization of a solid fuel pilot plant. 5 prototypes were made until the final one was reached, and on it were made experimental determinations for the study of combustion, energy efficiency and pollution degree.

1. THE CURRENT STATE OF THE RESEARCH IN THE TOPIC OF THE PROPOSED THESIS

The global need for energy and associated services is growing to keep pace with the demands of human, social and economic progress, well-being and health [59], [138]. All states depend on energy services to meet fundamental human needs. In the current international context that is strongly marked by the energy crisis and international tensions, the study of various authors has led us to the conclusion that green energy from renewable sources offers alternatives for global sustainable development.

In the future, sustainability will guarantee energy supply and reduce the impact of the energy sector on climate change [80], [127]. Green energy is an important issue in the debates on sustainable development, environmental, social and economic issues [43], [103]. According to the literature [47], [90], green energy sources have the potential to significantly reduce greenhouse gas emissions caused by the combustion of fossil fuels in power plants and beyond, and this could ultimately lead to a reduction in climate change. Now, more than ever, the demand for energy is increasing, yet conventional sources are finite and rapidly reducing [69]. At the same time, some types of resources are more difficult and risky to exploit than others [77], [108], and the discovery of new sources and the process of extracting resources become significantly challenging and costly [22], [166], [124]. In addition, people's quality of life is influenced by issues such as climate change, the energy crisis caused mainly by rising oil prices, international tensions between different states [71] and the global lockdown caused by COVID-19.

At the same time, in addition to those listed above, events such as unpredictable and severe weather will cause excessive heating/cooling demand in buildings [6], which together with changes in average weather models will have an impact both directly and indirectly on the performance of energy systems [8].

Currently, one of the most important problems at global level is the use of renewable energy resources to obtain clean fuels. In this context, one of the means to obtain energy from biomass is the use of waste materials that may or may not be pre-treated for this purpose [45], [111].

An important aspect related to the topic treated in this paper is the fact that the use of biomass for energy production has increased significantly in recent years, as part of the global strategy to reduce our dependence on fossil fuels [134]. Solid biomass covers a multitude of materials generated by industry, processes or directly supplied by forestry and agriculture such as: firewood, wood chips, sawdust, chips, biogas, animal waste or other solid plant residues, among others, which are mainly used to produce heat and electricity [36]. Wood pellets and briquettes are made by compressing dry sawdust or pieces of wood under high pressure. The densification process increases bulk density and facilitates logistics, transport and handling of the operation [107]. The use of wood pellets as a solid fuel is growing rapidly around the world [73].

In 2019, the world's pellet production accounted for more than 55.7 million tonnes [21], surpassing the prediction made by the European Biomass Association, which stipulated that by 2020 the consumption of biomass pellets at European level will reach a value of over 50 million tonnes in all European countries [29].

In this context, biomass is considered to be a renewable energy source that can be used in different applications in both domestic and industrial fields, being considered an energy carrier with neutral CO_2 content [68]. Currently, as an aside to the above aspect, we can observe an increase in the pellet market at a global level but also at the level of European countries and the new quality standards for biofuels, together with modern improved systems for optimizing the amount of air and fuel related to combustion processes, lead to a decrease in polluting emissions.
Biomass can be used in combustion plants of all sizes: small stoves and boilers in single-family homes, central heating in small dwellings and thermal power plants of medium and large size [140].

Given the complexity of the topic, the current state of research can be considered from several points of view, as follows:

a) from the point of view of the use of renewable energy sources,
b) from the point of view of biomass combustion,
c) from the point of view of the transformation of biomass into pellets/briquettes,
d) from the point of view of air quality issues,
e) in terms of applications and technologies used in biomass combustion plants.

3. OPTIMIZATION OF THE LINE AND OF THE PELLETIZATION / BRIQUETTING PROCESS

The objectives of this chapter are:

- Presentation of the technological line for the production of pellets/briquettes from a micro-enterprise of the profile
- Changes/improvements to some elements of the technological line
- Optimization of the technological process for the production of pellets / briquettes from biomass
- Transfer of the results obtained to another undertaking
- Identifying solutions for the sustainable development of the company.

As **results** of this research chapter can be stated:

- making a twig shredder (prototype possible to be patented),
- changes made to: straw shredders, firebox of drying oven, hoppers with dust separators, mixer, conveyor / grinder for pellets,
- technological line optimized for the production of pellets from mixtures,
- technological line optimized for the production of briquettes,
- new technological line for preparation and grinding supply of a steam boiler,
- prerequisites for the further development of the firm.

In this chapter was presented the proposal to optimize the technological line for the production of pellets existing at the factory in Cenei village. The optimization of the line was done after theoretically studying the entire process of obtaining pellets / lighters, after making technological visits to pellets / briquettes production plants and after discussions were held both with the managers of the companies and with the operating staff of the technological lines.
Initially, this technological line was made up only of the essential components for the operation of the factory, namely: shredder, hammer mill, drying plant, press bunker, briquette press, pellet press, pellet sieve and cooling, weighing and packaging plant [97].
The improvements made to the pellet and briquette line were made as follows: some to reduce manufacturing costs, others to diversify production and, most importantly, they were to eliminate risks, improve the quality of the working environment and reduce time without

production.
The improvements to *reduce the cost of manufacturing* were: storage of the raw material in protected spaces, management of various electric motors with a converter, which in addition to the regulating role also has the role of soft start, respectively changing the sites for the shredder and for the pellet press.
The improvements for *the diversification of production* were: two shredders, two bunkers, a mixer and an additional small pellet press were integrated into the technological line.
The improvements to *eliminate the risks* were: changes to the firebox of the drying plant and the separator mounted at the end of the drying line, operator safety elements (panic buttons, start / stop pedal, barriers to limit access).
The changes made to *improve the quality of the working environment* were: dust separators and dust filters, exhausters in areas where dust or smoke appears.
Following the modernization process [96] (for the diversification of the raw material, the increase of production and the improvement of the working environment) the line was equipped with:

- a shredder for twigs (**prototype made, to be patented**). Thus the branches are shredded before entering the hammer mill,
- yet another shredder. So the line will have two agricultural residue shredders for the two types of round bales,
- new site of different sizes for the hammer mill,
- bunkers equipped with cyclone dust separator. The line will have two bunkers where two different types of biomass will be stored simultaneously,
- a mixer. Because it was intended to make pellets and briquettes from at least two different types of biomass,
- pellet press of small capacity. In order to be able to make small-scale attempts, a small-capacity pellet press was purchased on which pellet recipes were produced,
- conveyor belt with scrapers. This tape replaces the auger conveyor that retrieves the pellets after the sifting and cooling plant for their transfer to the dosing and packaging equipment. This replacement reduced the amount of dust/pellets in the bags with the finished product.

Through the modernization process [96], improvements have also been made, both to the pellet line and to its machines, as follows:

- frequency converters for the two agricultural waste shredders. With their help we can control the amount of chipping that enters the hammer mill,
- mechanical dispensers at the bottom of the two bunkers, their advantage lies in the fact that at the beginning of the grinding process and transfer from the mill to the hopper there is no dust coming out in the hall at the bottom of the bunkers,
- constructive changes to the firebox of the drying line for the shredded raw material. By raising the firebox wall and adding 2 (two) phased sieves, the risk of ignition/explosion of biomass dust in the stream is reduced,
- addition to the mixer of a water dosing plant. If the biomass has too low humidity, its humidity may be increased as a percentage during mixing,
- adding two converters to the pellet press. One converter is in the engine that drives the power park and the second is in the engine that drives the dosing nozzle. By mounting these converters, the risk of blocking the pellet extrusion sieve is reduced.

On the optimized pellet line, the pellets were made, which were consumed in the pilot heating plant (in all its prototypes), in the plant purchased for the study of thermal efficiency, but also in a CHP unit.
Starting from the idea described in [113] and from the results obtained for the optimization of the pellet manufacturing technological line, a technological line was developed at COLTERM

SA for the biomass supply of steam boilers (100 t/h), because it was intended to supply the boiler with a mixture of biomass and coal, as shown in the following figure [113].

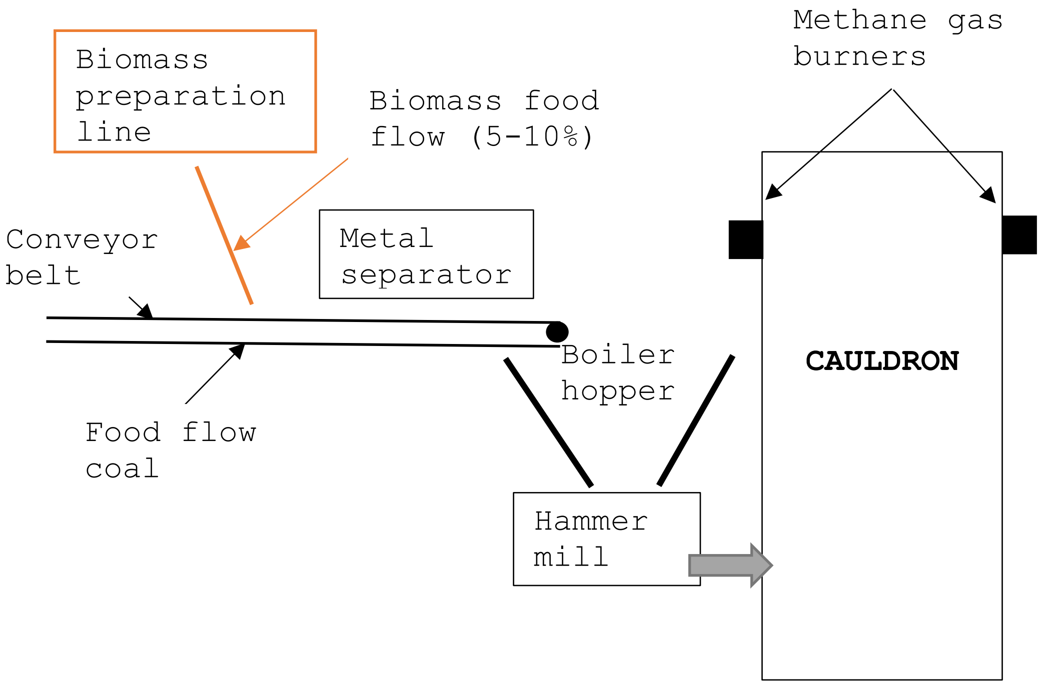


Figure 3.1. Diagram of a boiler fed with a mixture of biomass and coal, using methane burners [113]

The process of preparing biomass for combustion together with coal consists of:
- primary chopping with the Grandini industrial twig and log shredder that is fed by a grapple,
- shredding with a hammer mill,
- transfer to the coal conveyor belt through a tube with the help of the mill fan,
- together with the coal gets to the bunkers of the boilers.

After completing all the operations and checking the operation of this line, the necessary documentation for receiving the permit for the use of biomass (mixed with coal) in the production of heat energy was submitted. In September 2022, the environmental permit allowing the use of biomass together with coal was obtained (Annex 2), and then the GHG permit was also updated. Following the GHG update, COLTERM does not pay pollution certificates for the burnt biomass.

4. DESIGN, DESIGN AND REALIZATION OF AN INNOVATIVE PILOT HEATING PLANT

The objectives of this chapter are:
- Defining and establishing the interoperability of the components necessary to create a digitally controlled pellet heating system,
- Identification of solutions for plant optimization,
- Identifying solutions for plant automation, for its easy integration into smart-home devices that allow users to automate several devices including a heating plant.

As results of this chapter of research can be stated:

- a final prototype of a heating plant,
- a heating plant automation system for the easy integration of the plant into smart-home devices,
- patent application.

Starting from the need to make an energy balance of pellets and briquettes as well as other types of biomass, in this work was made a prototype that managed to gasify these materials, being the first prototype of the burner. Through successive tests, the prototype number 5 was reached, which is an automated heating plant in which any type of solid fuel can be burned, being easily integrated into an intelligent heating system of a home.

In this chapter are presented the 3 prototypes of burners and the 2 physical prototypes of the thermal power plant designed and physically realized during the doctoral training, on these prototypes were made gasification tests and burning of solid fuels.

The new solutions proposed and realized during this period are:

-firebox designed for the complete combustion of solid fuel and the reduction of the resulting amount of ash, as well as of deposits, being able to burn even energy willow with bark,

-3 serpentine hydraulic heat exchangers, exchanger 3 being an superheater for lowering the temperature of the flue gases,

-separating the flying ash from the flue gas and collecting it,

-complete automation of the plant for its integration into smart-home devices.

For the design of the pilot plant, we started from a scheme of principle shown in Figure 4.1 and reached a plant project (Figure 4.2) for which a patent application was filed in 2022.

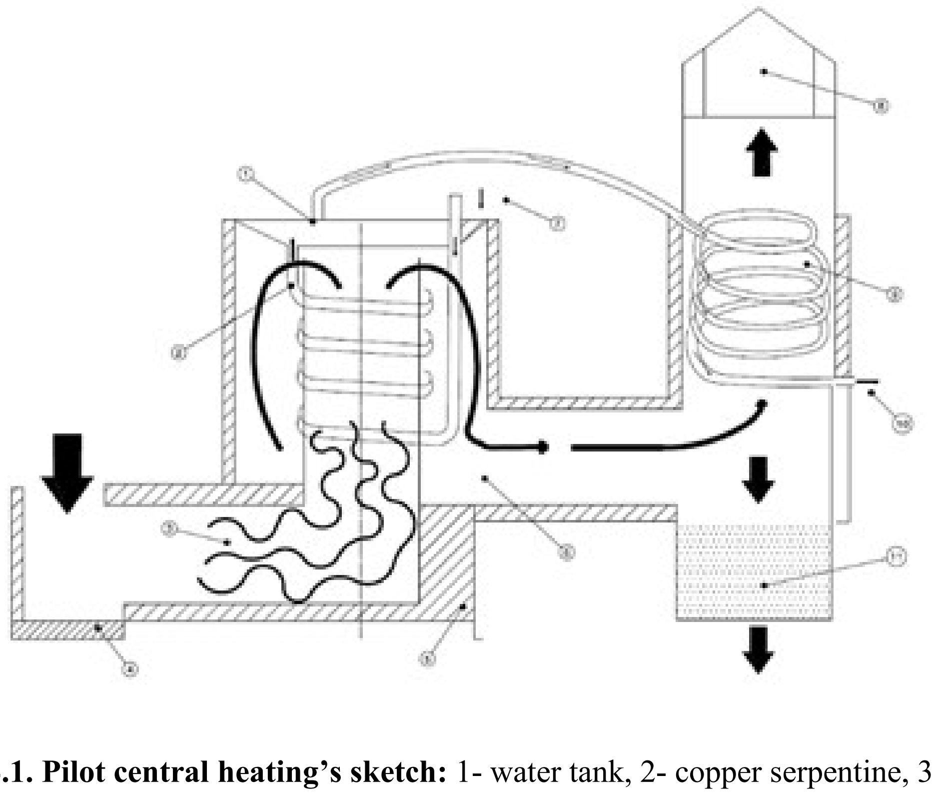


Figure 4.1. Pilot central heating's sketch: 1- water tank, 2- copper serpentine, 3-burning firebox, 4-ashes box, 5-insulation, 6-gas channel, 7-return, 8-furnace, 9-copper overheating, 10-tour, 11-flying ashes

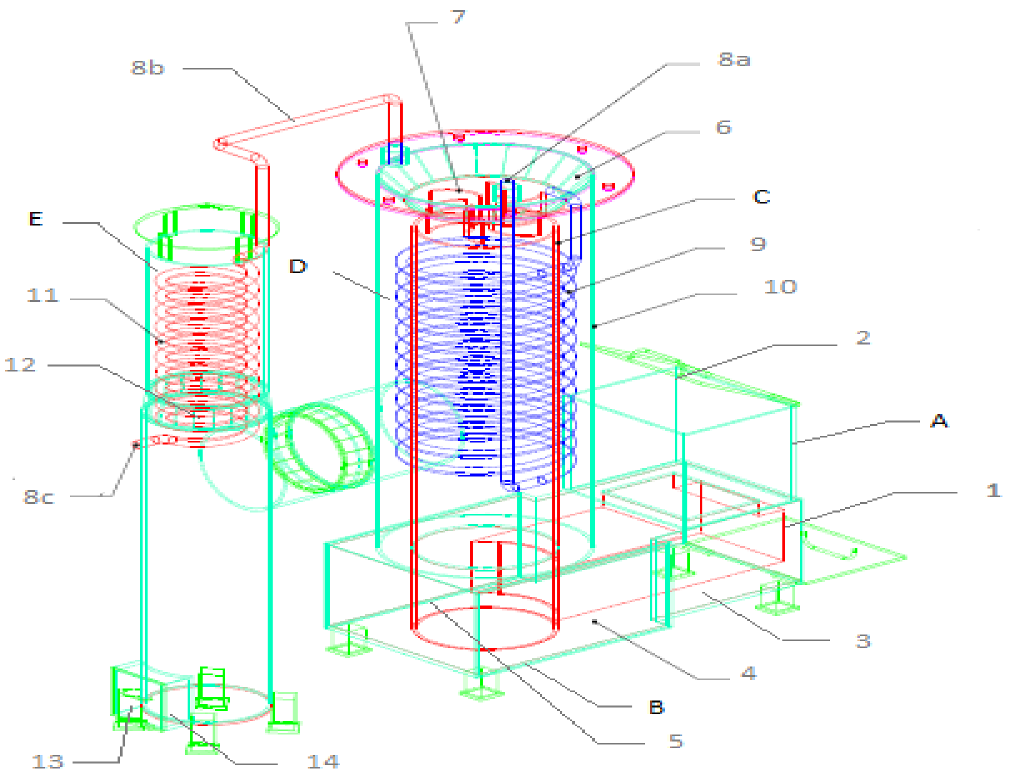


Figure 4.2. 3D central heating assembly: A – supply area, B – firebox, C – The first road of the flue gas, D – The second road of the flue gas, E – the third road of the flue gas, 1 – the firebox cleaning door, 2 – the central supply door, 3 – the ash
4 – deflector, 5 – lower insulation, 6 – heat exchanger 1, 7 – fins, 8a – power connection (RETURN)

The final prototype of the plant is shown in Figure 4.3, and in Figure 4.4 the power plant in operation with the automation part is presented.

Figure 4. 3. Pilot heating plant: 1-supply tube, 2-firebox, 3-plant body

Figure 4.4. Experiments in progress for connected plant automation

5. EXPERIMENTAL RESEARCH OF THE ENERGY EFFICIENCY AND ENVIRONMENTAL INFLUENCE OF THE PILOT PLANT

The objectives of this chapter are:

- establishing a methodology for experimental research on raw materials
- conducting experiments to determine the properties of raw materials for heating purposes and their analysis
- establishing a methodology for the experimental research on the process of burning raw materials in the pilot heating plant
- carrying out experiments in order to determine the results necessary for the study of the energy efficiency and the environmental influence of the pilot plant

The results obtained are:

- a research methodology,
- a database of raw materials that can be used as solid fuel in which the results obtained by processing experimental data were used, but also data from the specialized literature
- a database of collected results.

In addition to the optimization of the pellet manufacturing line described in Chapter 2 and the realization of the pilot plant described in Chapter 3, for the study of the energy efficiency of the pilot plant it was also necessary to know the physico-chemical properties of the raw materials that were burned in the plant, including the two types of pellets made on the technological line (with the small pellet press).

A research methodology was developed and the samples were prepared for laboratory analysis (raw materials and pellets). They were analyzed both in the private laboratories in Vienna, in the laboratories at UPT, and in the laboratory at COLTERM SA. As a result of the research, a database has been developed which will be used in the next chapter.

The prototype power plant 5 was connected to the heating system of a private home and replaced 2 gaseous fuel boilers (system with 10 radiators), the measurement points were determined (Figure 5.1) and the equipment, instruments and measuring devices were installed/ prepared.

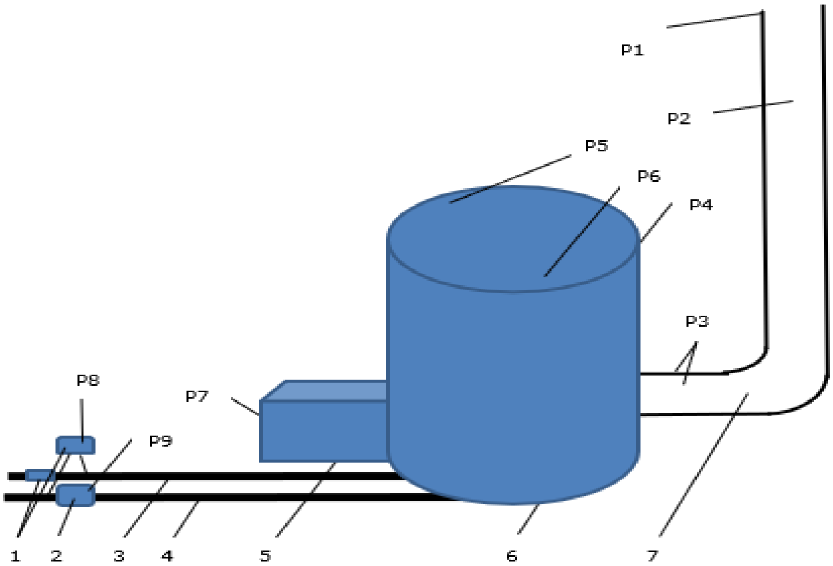
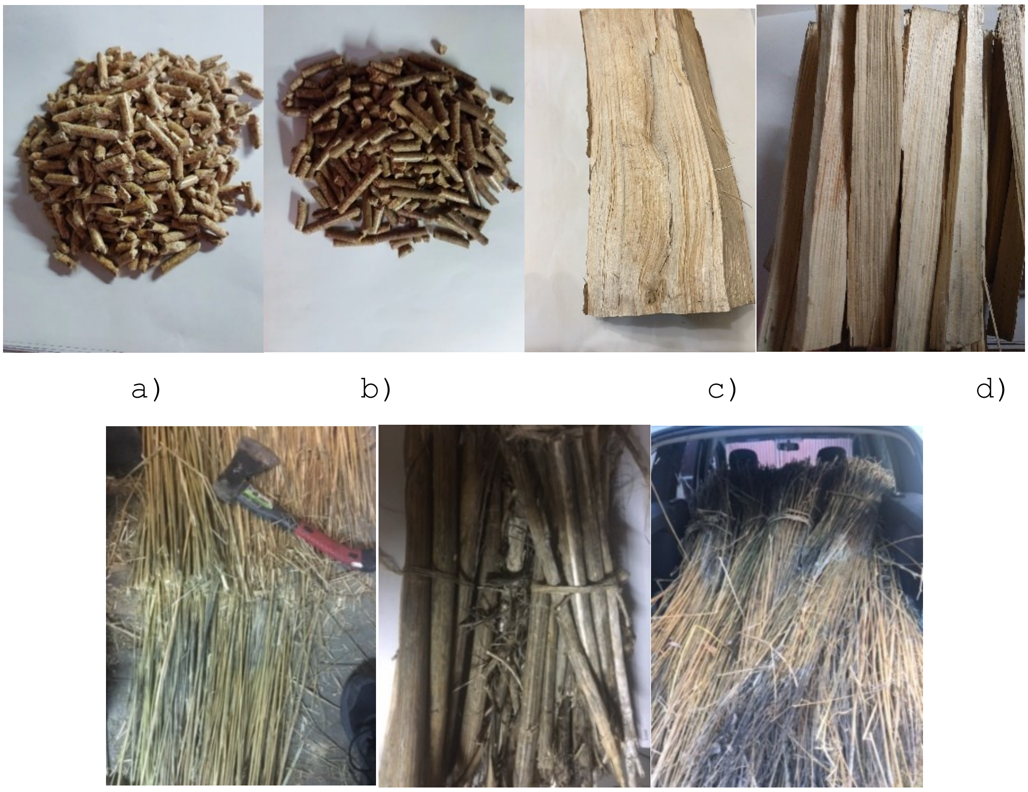


Figure 5. 1. Sketch of the heating installation (pilot heating plant) with the measuring points: 1-multical meter, 2-pump for recirculation of the heating agent, 3-return water, 4-lap water, 5-firebox, 6-central mantle, 7-gas exhaust chimney

Were made 7 series of measurements (5 types of raw materials, Figure 5.2) and the results were collected in a database to be used in the next chapter.



e)

Figure 5. 2. Materials chosen for the combustion process: a)resinous pellets, b)beech pellets with fir, c)hornbeam, d)resinous, e)hemp

Research keep going on:
- modifications to the automation for burning pellets so that they can also lead to the combustion of biomass grinding, taking into account that pelleting is an energy-intensive operation,
- conversion of the pitot plant into a steam generator for cogeneration (heat and electricity),
-increasing the amount of biomass burned in the steam boilers at CET SUD by mounting pellet burners on them (solution 2 of the work [113]).

6. PROCESSING OF EXPERIMENTAL DATA

The objectives of this chapter are:

- Determination of the inputs and outputs to be analyzed following the field experiments,
- Design of databases to be used in the calculations,
- Determination of functional relationships between previously established inputs and outputs in order to extract relevant information on the dependence of output parameters on controllable factors (inputs),
- Determination of a relationship for the calorific value of a solid fuel according to its elemental composition and its humidity,
- Training a neural network to return the elemental composition of a solid fuel according to its humidity, the mass percentage of residual ash resulting from the combustion of the fuel and its calorific value. The elemental composition of the returned fuel by the artificial neural network will be used together with its humidity in the formula determined for the calorific value, and the results will be compared with the values obtained experimentally for 5 raw materials.
- Study of the flow of heat agent for heating in heat exchangers.

The results obtained are:

- a database with the properties of the various raw materials that can be used as solid fuels or can be subjected to the technological process of pellet
- a neural network to determine the elemental composition of a solid fuel if its humidity, residual ash resulting from combustion and calorific power are known.

In this chapter, the data obtained experimentally, using statistical and artificial intelligence methods, were processed.
An important step in this regard was the pre-processing of data. This consisted of developing the databases used and determining the input and output variables associated with the experiments.
With statistical means, a formula for calculating the calorific value was determined based on the humidity and elemental composition of the combustible material, which has an accuracy of 99.4727%.

$$Calorific\,power = -39{,}5703 \cdot Humidity + 100{,}365 \cdot N + 329{,}299 \cdot C - \\ - 683{,}714 \cdot S - 74{,}1666 \cdot H + 78{,}4107 \cdot O \qquad (6\text{-}1)$$

Also with statistical means, functional relations were determined between the input and output variables recorded in the experiments, relationships that allow the establishment of new properties of the thermal power plant.
In the following figure, such a dependence is shown for the variation in the temperature of the flue gases at the outlet of the plant (Y5) on the energy of the fuel introduced (X1), the humidity of the fuel (X2) and the time carried out since the beginning of the experiment (X6), according to the relationship below.

$$Y5 = -7.02429 \cdot X1 + 2.2046 \cdot X2 + 2.91893 \cdot X6 + 0.356027 \cdot X1 \cdot X2 - 0.0278506 \cdot X1 \cdot X6 - 0.125091 \cdot X2 \cdot X6 + 0.0652596 \cdot X1^2 \quad (6\text{-}2)$$

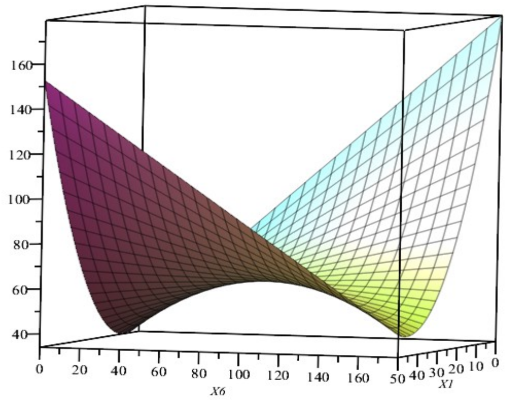


Figure 6.1. Variation of Y5 depending on X1 and X6 when X2 = 17.03558343

An artificial neural network was trained to determine the elemental composition of a material, based on its calorific power, humidity and the amount of residual ash resulting from the combustion of this material. The calculation was done using the Neural Network Toolbox in Mathlab [99].

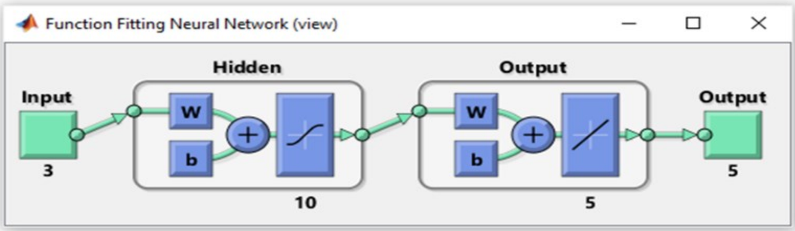


Figure 6. 2. Neural network structure

The 3 inputs of the neural network can be established relatively easily, using a humidity meter and a calorimetric bomb. To establish the elemental composition, more complex analyzes are needed that are not necessarily at hand.
The neural network, with an accuracy of 99.96%, was additionally validated by calculating the calorific value related to some innovative raw materials used in combustion tests in the plant, using the elemental composition provided by the neural network and the statistically determined regression equation (Figure 6.3).

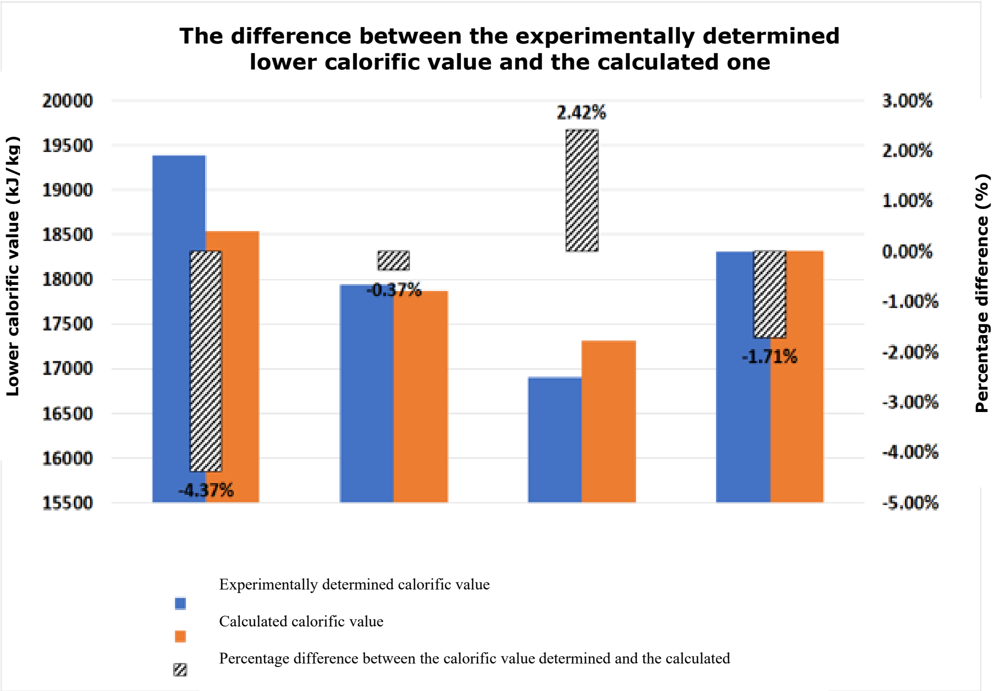


Figure 6. 3. The difference between the experimentally determined lower calorific value and the calculated one

By improving the final prototype of the heating plant, the amount of CO (fuel) eliminated into the atmosphere was reduced by almost half, as shown in the figure below.

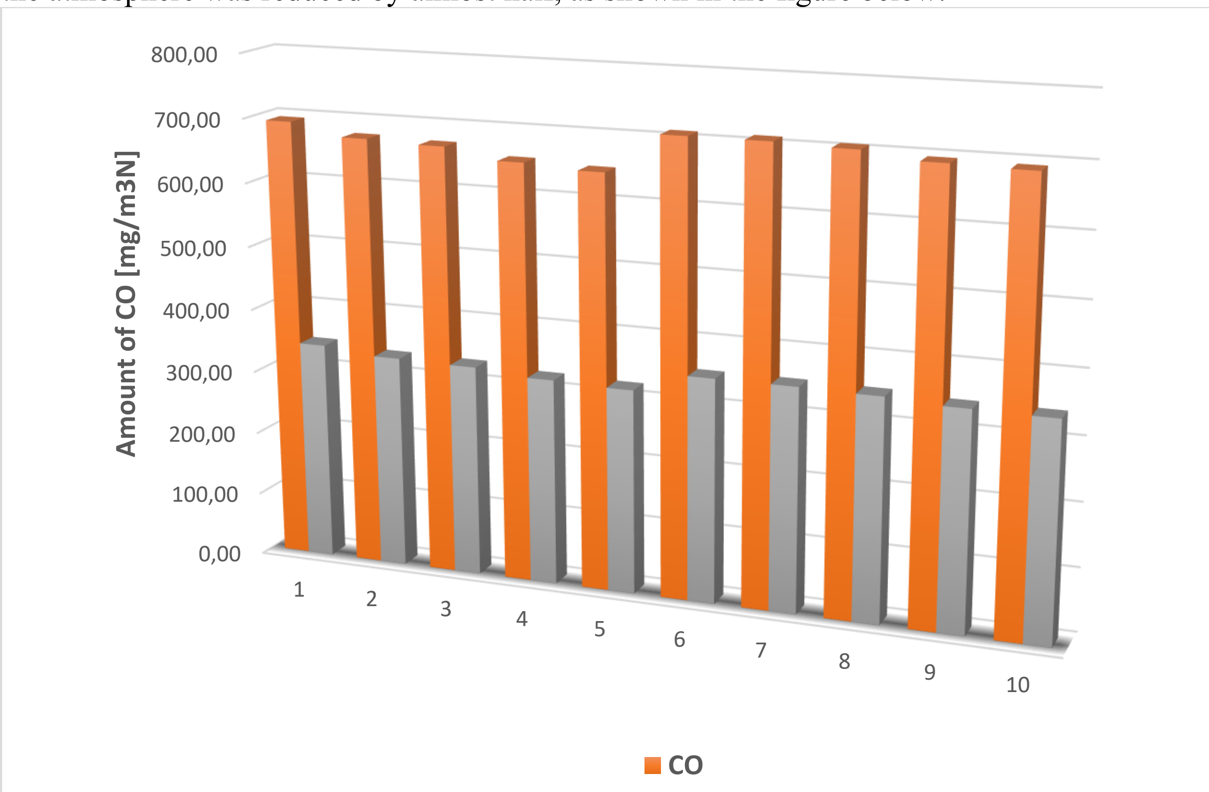


Figure 6. 4. Amount of CO in mg/m^{3}N for prototype 4 and 5 for the 10 samples

From the simulation process carried out with the commercial program Ansys – Fluent variant 2019R1[7] it results that the value of the temperature difference obtained by numerical simulation is close to the result obtained by experimental measurements. As a result of these simulations, the serpentine-type heat exchanger is preferable to other types of exchangers.

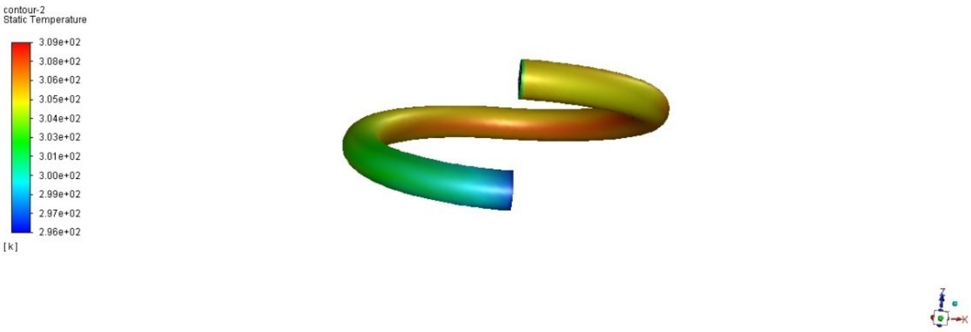


Figure 6. 5. Temperature field

7. GENERAL CONCLUSIONS. PERSONAL CONTRIBUTIONS. RESEARCH PERSPECTIVES

General conclusions

Starting from the need expressed by a company operating in the field of pellet and briquette production, the present research has brought an innovative solution in terms of both optimizing the technological line of pellets / briquettes production, as well as for burning the products obtained by the company.

Personal contributions

This work brings a series of personal contributions of a theoretical, experimental or industrially applicable nature, based on documentary studies, theoretical modeling and experimental research carried out during the doctoral training period.

The original results obtained from **the process of optimizing** the technological line are made up of:

-an innovative shredder for shredding twigs,

- a mixer for the homogenization of biomass mixtures,

-intermediate bunkers for various raw materials,

-increasing safety (changing the firebox of the dryer) and improving the working environment (dust filters),

-obtaining a continuous flow production,

-transfer of the results by creating a biomass preparation line for burning together with coal at CET SUD.

As original results obtained as a result **of the design and physical realization** of the heating plant are:

-an optimized pellet/lighter manufacturing technology line,

-an innovative pilot heating plant for which a patent application has been submitted,

-an automation system of the pilot heating plant for its easy integration into smart-home devices.

As original results obtained from **experimental research are** to be mentioned:

-Factory verification of the making of pellets from various recipes after optimizing the manufacturing process. On the technological line, tests were made to optimize the production process, then the pellets were produced, which were burned in the 5 prototypes of the pilot plant .

-checking the energy efficiency of the pilot plant. Experimental determinations were made on the final prototype of the plant after it was integrated into a heating system with 10 radiators.

Theoretical contributions

The main contributions of a theoretical nature are:

• **critical coverage of the specialized literature** both in the field of biomass and in the field of thermal power plants. From the study of 140 bibliographic sources was presented the current state of research in the studied field,

• **building a biomass database that can be used as a combustible material**. The database was created following research in the literature, own determinations and field research. These results contribute to the achievement of the PO1 primary objective and the SO1 sub-objective.

• **building a neural network** that predicts the calorific power and the amount of residual ash starting from the elementary composition of a material. These results contribute to the achievement of the PO1 primary objective and the SO1 sub-objective.

• realization of the technical project of the power plant

Experimental contributions

The main contributions of an experimental nature are:

- **verification of the operation of the technological line of pellets / briquettes** following optimization. This result contributes to the achievement of the PO1 primary objective and the SO2 sub-objective.
- **technical realization of the heating plant** for individual dwellings based on the prototype project. This result contributes to the achievement of the PO2 primary objective and the SO3 and SO4 sub-objectives.
- **verification of the operation of the prototype heating plant** for individual dwellings. This result contributes to the achievement of the PO1 and PO2 primary objectives and the SO1 and SO3 sub-objective.

Contributions applicable to industry

The main industrially applicable contributions are:

- premises for optimizing the technological line of pellets / briquettes. This result contributes to the achievement of the PO1 primary objectives and the SO2 sub-objective.
- the possibility of building the pilot heating plant on an industrial scale. This result contributes to the achievement of the PO1 and PO2 primary targets and the SO1, SO3 and SO4 sub-targets.
- the possibility of automating the prototype heating plant and integrating it into the smart home. This result contributes to the achievement of the PO1 and PO2 primary objective and the SO3 sub-objective.

The results of the research were disseminated through:

-Increasing the contribution in the field of knowledge by publishing articles: 2 in ISI journals, 4 in proceedings at ISI quoted conferences, 2 in BDI quoted journals and 1 in proceedings at BDI quoted conferences,

-Collaboration with SC TITUS INDUSTRIES SRL, which is directly interested in the results of the research. Within this company, the technological line for the production of pellets/briquettes has been optimized,

-Collaboration with SC COLTERM SA, where a technological line has been developed and solutions are being sought to increase the biomass intake in the energy mix (coal-biomass).

Prospects for further development

Following the experience gained, we have identified three main directions of research:

A. Improvement of the technical solution for the plant and the complete study of combustion as follows:

- the introduction of another heat exchanger,
- construction of the firebox from a more resistant material,
- full study of combustion in such individual plants (major concentrations, potentially toxic elements and phase composition of ash).

B. Transforming or coupling the plant as follows:

- coupling of the plant with thermal storage devices;
- the transformation of the plant into a micro-cogeneration system using, for example, a Stirling engine. This plant can easily be modified into a technological steam generator capable of operating a cogeneration engine/mini-turbine;
- realization of a 100% renewable hybrid system: photovoltaic panels in prosumer contract and cogeneration that can operate during the autumn-winter period when the electricity production of photovoltaic panels is reduced.

C. Installation of pellet burners on the CET SUD steam boiler to increase the biomass ratio in the biomass mixture (now the maximum is 10%).

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