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Transforming vegetables waste into energy: development and optimization of an automated briquette-producing prototype

Transformando residuos vegetales en energía: desarrollo y automatización de un prototipo automatizado para la producción de briquetas

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Abstract: The project introduces an innovative electromechanical prototype aimed at valorizing vegetable waste through automated briquette production. The study optimizes pressure and temperature parameters, utilizing control devices such as frequency inverters and electric resistors. Integration of Modbus RTU communication infrastructure ensures efficient and monitored processes. Employing a Koyo CLICK PLC and an HMI facilitates smooth execution, laying groundwork for future energy generation innovations. The research underscores the importance of energy sustainability and reducing the global carbon footprint through biomass management and utilization. Findings highlight the prototype's effectiveness in transforming waste into energy, optimizing processes for increased efficiency. Study conclusions emphasize the potential for widespread adoption of similar technologies to address environmental challenges and promote sustainable practices in waste management and energy production.

Keywords: Electromechanical prototype, automated production, energy sustainability, waste valorization.

Resumen: El proyecto presenta un innovador prototipo electromecánico destinado a valorizar residuos vegetales mediante la producción automatizada de briquetas. El estudio optimiza parámetros de presión y temperatura, utilizando dispositivos de control como inversores de frecuencia y resistencias eléctricas. La integración de la infraestructura de comunicación Modbus RTU garantiza procesos eficientes y monitorizados. El empleo de un PLC Koyo CLICK y una HMI facilita la ejecución fluida, sentando las bases para futuras innovaciones en generación de energía. La investigación subraya la importancia de la sostenibilidad energética y la reducción de la huella de carbono global mediante la gestión y utilización de biomasa. Los hallazgos destacan la eficacia del prototipo en transformar residuos en energía, optimizando los procesos para aumentar la eficiencia. Las conclusiones del estudio enfatizan el potencial de adopción generalizada de tecnologías similares para abordar desafíos ambientales y promover prácticas sostenibles en la gestión de residuos y la producción de energía.

Palabras clave: Prototipo electromecánico, producción automatizada, sostenibilidad energética, valorización de residuos.

1. INTRODUCTION

Currently, the briquette technology in Colombia faces challenges in technical optimizations. However, the urgency to reduce dependence on fossil fuels and to combat climate change has generated interest in biomass as a sustainable source of heat and energy [1]. A concurrent problem is the accumulation of agricultural and forestry waste that, instead if reused, they contribute to pollution [2].

Within the spectrum of renewable energies, biomass stands out due to its wide availability and its ability to offer ecological and socioeconomic benefits [3]. In particular, plant waste has a high energy potential, especially when transformed into briquettes. These briquettes, when incinerated, release heat due to their thermal properties acquired during the compaction process.

Briquetting is a technique that compacts agricultural waste, with or without a binding agent, producing solid, dense structures through the application of pressure. Despite the obvious benefits of briquettes as wood substitutes, limitations in machinery and technology transfer in many developing countries have hindered their large-scale adoption [4].

Before this challenge, the study proposes for development of an automated prototype of the briquetting of vegetable waste, using the Modbus RTU protocol. The purpose of this study is to establish a starting point for future research on energy generation using economical biofuels.

2. THEORETICAL BASE

2.1. Vegetables waste as a source of energy

According to Romero [5] “The name biomass refers to a heterogeneous set of organic materials, both due to their origin and their nature and composition, which can be used to obtain energy.”

On the other hand, vegetable waste, the main product of agricultural and forestry activities, has traditionally been underutilized, often being discarded or used for composting [6]. However, in the contemporary era of sustainability, this waste has attracted attention for its potential as a renewable energy source. On the other hand, it is highlighted that the energy use of these wastes can be a viable response to the growing demand for sustainable energy sources and reduction of the environmental impact associated with the use of fossil fuels [17][18].

2.2. Briquettes: compaction and energy potential

Briquettes represent an innovative solution to convert plant waste into fuel [7]. This type of solid biomass is the result of a densification process and is mainly composed of organic matter of vegetable origin, coming from various sources such as agriculture, industrial waste, food industries, among others, according to Ramírez [8]. Its manufacturing process, which involves compaction and drying, gives the briquettes superior density and energy efficiency compared to the material in its original state. This approach not only offers a sustainable alternative for the use of vegetable waste, but also contributes significantly to the mitigation of environmental pollution and the reduction of dependence on fossil fuels [19][20].

2.3. Briquetting process and its relevance

Briquetting represents the crucial process by which plant waste is converted into briquettes, an essential stage in their manufacturing. As mentioned in several studies [9], [10], [11] "Briquetting is the cornerstone in the briquette production cycle." This procedure involves various phases, ranging from the preparation and treatment of the base material to its compaction into specific shapes. The standardization and optimization of this process is essential to guarantee the quality and energy efficiency of the briquettes generated.

2.4. Automation in briquette production

The growth in demand for briquettes as an energy source has driven the need to automate their manufacturing [12][13]. By implementing advanced technologies, it is feasible to optimize and standardize the process, resulting in a significant increase in productivity and ensuring consistency in the quality of the final product [14][15][16].

3. METHODOLOGY

Within the context of this study, the project is organized into two fundamental dimensions: the evolution of the design and the complete automation of the briquetting process. Next, the components of the prototype to be developed will be detailed along with their respective operational functions:

3.1. Grinding Unit

This section is made up of several key elements, including: a hopper, a motor equipped with a reduction box that is linked through a spider-type design coupling, complemented by a worm gear mechanism and a belt drive (see Fig.2).

3.1.1. Hopper:

It is a compartment or container generally conical or pyramidal in shape. It is used to store raw materials (such as grains, powders, etc.) and guide them towards the grinding system thanks to gravity.

3.1.2. Motor with reduction box:

A motor converts electrical energy into mechanical energy, allowing the moving parts of the machine to operate. The reduction box, on the other hand, is a mechanism that is coupled to the motor to reduce the rotation speed. This is useful in applications where a slower turn is needed, but with greater force or torque.

3.1.3. Spider coupling:

It is a type of connection between two rotating axes that allows the transmission of motion. It is called "spider type" because its design, which usually includes elastic elements that resemble legs, allows it to absorb vibrations and misalignments between the connected axles.

3.1.4. Endless screw:

It is a type of gear that consists of a screw (which rotates) and meshes with another gear, usually called a worm wheel. The worm gear allows for smooth transmission and can change the direction of rotation. It is common in systems where speed needs to be reduced and torque increased.

3.1.5. Belt drive:

Belt drive works on the principle that when a belt is wound around a drive pulley and set in motion, it transfers motion and power to one or more pulleys driven by friction.

3.2. Compaction Unit

This unit integrates a three-phase motor that, through a gear mechanism with a toothed chain, drives the compaction cylinder. The cylinder is equipped with a steel ramp designed to direct and facilitate the transfer of the previously crushed material towards the compactor, as seen in figure 2. By applying a specific force, said material is compacted, resulting in the production of briquettes. at the end of the process.

3.3. Drying Unit

In this stage, the previously compacted material is subjected to a thermal process using clamp-type electrical resistances. This exposure to elevated temperatures for a certain period guarantees the elimination of moisture and optimizes the physical properties of the briquettes.

3.4. Process Automation

For automated management, an advanced control panel has been incorporated (see Fig. 3). This integrates a Human-Machine Interface (HMI), a frequency converter, a Programmable Logic Controller (PLC), limit switches, and an emergency stop button. In addition, specific protection elements have been added. This configuration allows the compaction pressure to be meticulously regulated, adjusting the speed of the motor associated with the compactor. Likewise, the temperature is controlled, facilitating the performance of experimental tests as the result displayed in fig 4.

4. RESULTS

A scale electromechanical prototype has been developed that has been automated through a control interface, using the Modbus RTU communications protocol. This interface has integrated a Programmable Logic Controller (PLC), a Human-

Machine Interface (HMI), a frequency converter and two motors, one of which is three-phase. In order to verify and document its optimal functionality, experimental tests were carried out.

Figure 1 shows the initial stage of the prototype design. Subsequently, Figure 2 shows the fully assembled prototype, while Figure 3 highlights the control interface integrated into the system.

These results demonstrate the viability and effectiveness of the developed prototype, as well as the adequate functionality of the implemented control interface. The recommendations from the experimental tests support the efficiency of the system in automating the briquetting process, thus laying the foundation for its possible implementation in larger scale industrial applications.

Fig. 1. *Initial stage in the construction of the prototype.*
Reference: *Authors.*

Fig. 2. *Assembled prototype.*
Reference: *Authors.*

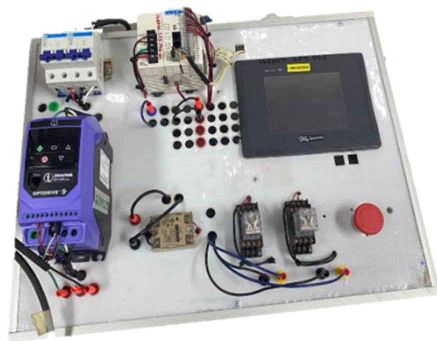

Fig. 3*. Assembled prototype.*
Reference: *Authors.*

Fig. 4. *Finished prototype*.
Reference: *Authors.*

5. CONCLUSIONS

After carrying out operational tests with a variety of plant residues, the system has demonstrated optimal preparation, positioning itself as a promising tool for subsequent experimental investigations.

The integration of a touch interface to the control panel, with an intuitive design and the inclusion of clearly distinguishable icons, not only improves user interaction, but also enhances the efficiency, productivity and reliability of the system.

Furthermore, the advanced configuration of the prototype ensures precise adjustment of critical parameters such as speed and temperature, resulting in the production of briquettes of exceptional quality. These conclusions support the viability and potential of the system developed for its application in industrial and research environments, highlighting its ability to contribute significantly to the optimization and efficiency in the recovery of plant waste through automated briquette production.

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