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DESIGNING AN EXPERIMENTAL PYROLIZER MODEL FOR THE PRODUCTION OF PHOSPHORUS–RICH FERTILIZERS FROM POULTRY MANURE

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Abstract: The increasing demand for sustainable agricultural practices highlights the need for efficient poultry manure management, as improper disposal can lead to environmental issues like water eutrophication and soil degradation. Pyrolysis offers a promising solution by converting poultry manure into valuable biofertilizers, such as phosphorus–rich biochar, which improves soil fertility and reduces the dependence on harmful chemical fertilizers. This process also mitigates greenhouse gas emissions and promotes long–term agricultural sustainability. This paper presents the design and implementation of a pyrolysis system (EP) aimed at processing poultry manure and other organic materials, such as plant residues, to produce phosphorus–rich biofertilizers. The equipment, developed within the second phase of an ADER project, was designed using a specialized CAD–CAE software, which facilitated the optimization of its design and performance. The pyrolysis equipment consists of several specialized components (reactor, combustion chamber, heating system, insulation, control system, etc.), all designed to convert poultry waste into biochar and biofertilizers in a controlled and efficient manner. The device reaches temperatures of up to 1150°C and is equipped with a four–stage air purification system that reduces emissions and unpleasant odors, contributing to environmental protection. By valorizing agricultural waste, the technology offers a sustainable solution for agriculture, with long–term economic benefits and a positive impact on the fertilization of nutrient–poor soils. The system ensures efficient material handling and temperature control through programmable controllers, enhancing the overall process. This work also highlights the environmental benefits of utilizing poultry waste for fertilizer production and the system's contribution to sustainable agricultural practices.
Keywords: pyrolysis, poultry, biofertilizer, waste, management

1. INTRODUCTION

The growing need for sustainable agricultural practices has highlighted the importance of efficient waste management, particularly in poultry farming. Poultry manure is a high–volume byproduct that contains substantial amounts of nitrogen, phosphorus, and other nutrients. If not managed correctly, these nutrients can leach into surrounding ecosystems, causing water eutrophication, soil degradation, and other environmental issues (Kumar et al., 2017; Sharpley et al., 2014). Traditional methods of poultry manure disposal, such as land application, can lead to nutrient runoff and greenhouse gas emissions (Haque et al., 2018; Zhang et al., 2021). Therefore, the need for alternative and sustainable solutions for the valorization of poultry manure is evident (Liu et al., 2019, Farag et al, 2024)).

In the context of orchards (like fruit trees or vineyards), fertilization is essential to maintain soil fertility and ensure healthy growth and high yields. Orchards often face challenges in terms of nutrient management because they require specific nutrients over a longer period. Unlike conventional fertilizers, which might be chemically synthetic and provide immediate nutrient release, biofertilizers created through pyrolysis offer a slow–release effect, ensuring that nutrients are available to the plants over an extended period.

Pyrolysis has emerged as a promising technology for transforming poultry manure into valuable products, such as biochar, biofuels, and biofertilizers. The process of pyrolysis involves the thermal decomposition of organic materials in the absence of oxygen, which results in the formation of

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solid, liquid, and gaseous products. In the case of poultry manure, the solid product, biochar, is rich in phosphorus, which is a crucial nutrient for plant growth and an essential component in biofertilizers (Zhang et al., 2018; Paredes et al., 2020). This biofertilizer can be used to improve soil health, enhance nutrient availability for plants, and reduce the dependence on chemical fertilizers, which are often associated with environmental harm and high production costs (Cai et al., 2020; Kammoun et al., 2020; Vladutoiu et al, 2025).
Moreover, pyrolysis provides additional environmental benefits by reducing the volume of waste and mitigating the release of greenhouse gases, such as methane and ammonia that are typically produced during manure storage (Rojas et al., 2020; Yao et al., 2018). In particular, the pyrolysis of poultry manure significantly reduces methane emissions compared to traditional storage methods (Chen et al., 2019). Thus, using pyrolysis to valorize poultry manure offers a dual benefit: it addresses waste management issues while simultaneously producing sustainable, phosphorus–rich biofertilizers that contribute to more resilient agricultural systems (Ravindran et al., 2021; Li et al., 2019).
The incorporation of poultry manure–derived biochar into agricultural soils has been shown to improve soil fertility, water retention, and microbial activity, offering a practical approach to soil remediation and enhancing long–term agricultural productivity (Lehmann et al., 2011; Zhang et al., 2019). Furthermore, studies have shown that biochar produced from poultry manure has the potential to sequester carbon in the soil, thereby contributing to climate change mitigation (Taghizadeh–Toosi et al., 2014).
Therefore, pyrolysis presents a sustainable and multifaceted solution to the challenges posed by poultry manure waste. By converting poultry manure into phosphorus–rich biofertilizers, pyrolysis not only helps manage waste but also promotes environmental sustainability and agricultural resilience (Roberts et al., 2020; Xie et al., 2018).

2. MATERIALS AND METHODS

The growing demand for sustainable agricultural practices and efficient waste management has led to the development of specialized equipment designed to process poultry waste into valuable by–products. The pyrolysis equipment, symbolized as EP, has been specifically designed and partially developed in the second stage of an ADER project, with the main objective of carrying out the pyrolysis process of poultry manure. This process not only transforms poultry waste into biochar but also serves as a means to obtain biofertilizers rich in phosphorus, essential for soil health and plant growth.

Key Functional and Structural Requirements

The pyrolysis equipment must meet the following requirements for optimal performance:
- Execution of Poultry Waste Pyrolysis: The equipment must be capable of carrying out the pyrolysis process effectively, turning poultry manure into valuable products like biochar.
- Control and Operation: It should be controllable from a central command and control panel, ensuring ease of operation and monitoring.
- Programmable Temperature Stages: The equipment should have programmable temperature stages, allowing for the adjustment of temperature based on specific pyrolysis needs.
- Batch Operation: It operates in batches, making it suitable for the cyclical nature of poultry waste production.
- Ease of Use: The system must be user–friendly, allowing for straightforward handling and operation without requiring extensive technical expertise.
- Loading Capacity: The pyrolysis reactor must have a loading capacity of approximately 40 kg of poultry waste (with a reactor volume of about 40 liters), making it efficient for medium–scale operations.

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- Recovery of Pyrolysis Oil and Synthesis Gas: The equipment must allow for the recovery of pyrolysis oil and/or synthesis gas, providing additional value by–products and contributing to a more sustainable process.

Purpose and Components

The pyrolysis equipment, denoted as EP, is a key component of the project and has been designed primarily for the pyrolysis of poultry manure, as well as other organic materials such as plant residues. The primary goal of the process is to produce phosphorus–rich biofertilizers.

The pyrolysis system is powered by a 10kW photovoltaic panel system, ensuring energy efficiency and sustainability. Additionally, it is equipped with an air purification system, consisting of a pre–filter and an activated carbon filter. This system plays a crucial role in eliminating unpleasant odors and potential harmful gases that may be produced during the pyrolysis process. The air filtration system ensures that the operation of the pyrolysis equipment complies with environmental standards and reduces the risk of pollution

3. RESULTS AND DISCUSSION

The pyrolysis equipment (Figure1) is composed of several key subassemblies, each playing a critical role in ensuring the efficient and safe operation of the system. These components, which will be described in more detail below, are as follows:

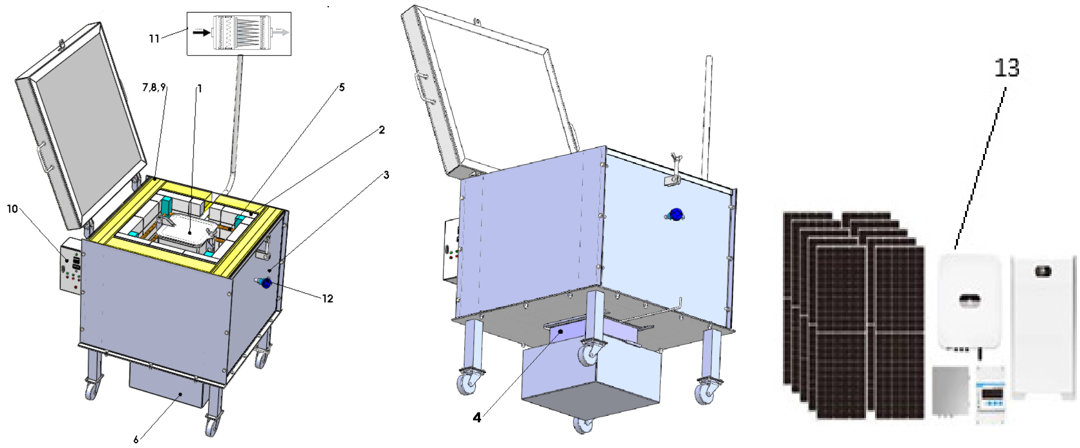

Figure 1 – The Pyrolysis Equipment. 1. Reactor, 2. Combustion Chamber, 3. Outer Casing, 4. Assembled Shelter, 5. Heating System, 6. Collection Box ,7,8,9. Insulation, 10. Control Panel, 11. Air Purification System, 12. Thermocouple, 13 Photovoltaic system

The Reactor (Figure2)

This is the core unit where the pyrolysis process takes place. The reactor is designed to handle the thermal decomposition of poultry waste and other organic materials in the absence of oxygen, converting them into biochar, gases, and liquids.

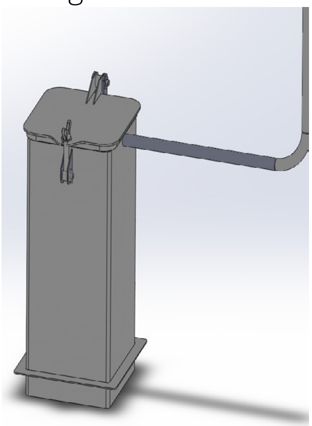

Figure 2 – Reactor

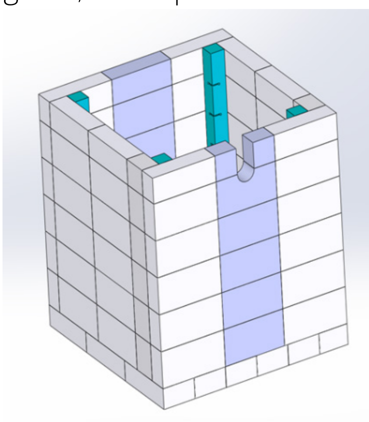

Figure 3 – Combustion Chamber

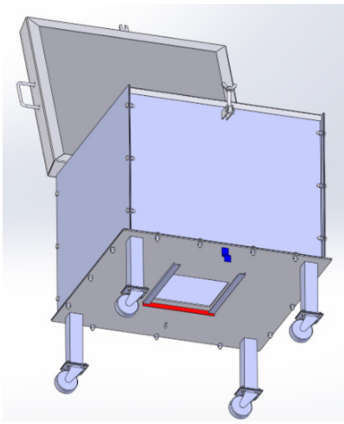

Figure 4– Outer Casing

The reactor is a metallic structure with a parallelepiped shape, made from AISI 310 refractory steel with a thickness of 5 mm, capable of withstanding temperatures up to 1150°C, providing a usable volume of 0.046 m³, intended for filling with poultry manure. It is equipped with a sealed lid secured

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by a ceramic cord. The lower part is welded with a support collar, allowing the reactor to be positioned and fixed within the Combustion Chamber *(Figure3).* The bottom section is open and designed for discharging the material resulting from the pyrolysis process, with a shelter that regulates the opening and closing of this discharge zone. On the top, there is a system for the evacuation of synthesis gases. Depending on the moisture content of the poultry manure, which can range from 10% to 80%, the reactor can hold between 18.4 kg and 57.5 kg of material.

The Combustion Chamber (Figure3)

The combustion chamber is responsible for maintaining the required high temperatures necessary for the pyrolysis process. It ensures efficient heat generation and distribution, contributing to the effective breakdown of the waste material.

The combustion chamber is constructed from JM 26 refractory insulating bricks, with internal dimensions of L x W x H = 550 x 550 x 650 mm, resulting in a total volume of 0.19 m^3. The refractory bricks, measuring 230 x 114 x 64 mm and having a density of 800 kg/m^3, exhibit a range of superior technical properties. These bricks can withstand temperatures up to 1450°C and have low thermal conductivity. The material demonstrates a compressive strength of 2.3 MPa and excellent resistance to thermal shock, with a thermal conductivity of 0.33 W/mK at 1000°C. The chemical composition of the material is as follows: Al_2O_3 (58%), SiO_2 (39.1%), Fe_2O_3 (0.7%), and it has a white color.

In the four corners of the combustion chamber, support pillars for the electric heating elements are placed. These pillars are specifically designed and cut to allow the optimal placement of the heating elements. The material used for the pillars is JM 26 refractory brick, and their dimensions are 50 x 50 x 650 mm.

The Outer casing (Figure4)

The Outer casing (4) is an assembled structure made from welded subassemblies. It is equipped with legs fitted with wheels to ensure the mobility of the equipment (two standard wheels and two with braking systems), appropriately sized to support the entire weight of the equipment (approximately 368 kg, excluding the material undergoing pyrolysis). The outer walls are detachable, which facilitates both assembly and disassembly in case of unforeseen situations.

At the top of the casing, there is a lid that ensures the sealing of the heated zone, thereby preventing significant heat loss. The lid is equipped with handles for easy handling and is lined with insulating materials, including 50 mm thick Cerablanket refractory ceramic fiber boards, which are resistant up to 1250°C, as well as a 50 mm thick Superwool Block 800 ceramic board. At the bottom of the casing, there is a cutout intended for the discharge of the fertilizer obtained from the reactor. The discharge slide moves along welded guide rails, thus facilitating the unloading process.

At the bottom, the equipment is provided with an *Assembled Shelter (Figure5*) that glides along two welded guide rails attached to the casing. This allows for the opening and closing of the discharge area, thereby facilitating the transfer of material into the *Collection box, (Fig 6).* This configuration ensures an efficient material handling process

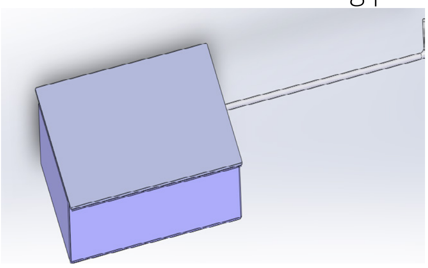

Figure 5. Assembled Shelter

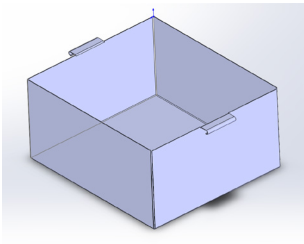

Figure 6. Collection Box

Heating System EP – 5.0

The pyrolysis furnace utilizes an electrical system that provides precise control over the temperature. This system also incorporates safety mechanisms to protect against overloads, ensuring both secure and efficient operation. This setup enhances the overall pyrolysis process, guaranteeing the desired outcomes.

At startup, the furnace is powered by a 400V three–phase cable, which is safeguarded by automatic fuses. These fuses are specifically intended to disconnect the power in case of an overload or short circuit, maintaining the system's safety. Inside the furnace, temperature control is managed by a programmable controller, model ART 2006, which receives input from a type S thermocouple. This thermocouple, composed of two different metals, generates a voltage corresponding to the temperature difference between its ends. The controller uses this voltage to regulate the power supplied to the heating elements, ensuring a stable and controlled temperature.

The controller allows the user to program both heating and cooling cycles at customized rates and maintain the temperature at present levels for specific thermal processes. Additionally, the system features an automatic start function, enabling a treatment cycle to begin at a set time.

The heating system consists of 6 electric heating elements arranged in 6 rows, totaling a power output of 19 kW. These heating elements are of the Kanthal A1 type, with a 2 mm thickness, a coil diameter of 22 mm, and an electrical resistance of 12.5 ohms. Each heating element has an electrical power rating of 3300W at 400V, specifically designed for the combustion chamber.

The pyrolizer is equipped with PtRh10%–Pt thermocouple, Type S (Figure9), has a length of 230 mm and a maximum measurement temperature of 1300°C. It is made from two different metals: 90% platinum and 10% rhodium for one conductor, and 100% platinum for the other. When these metals are welded at one end and exposed to a temperature difference, an electrical voltage is generated that is proportional to this difference, allowing for precise temperature measurement.

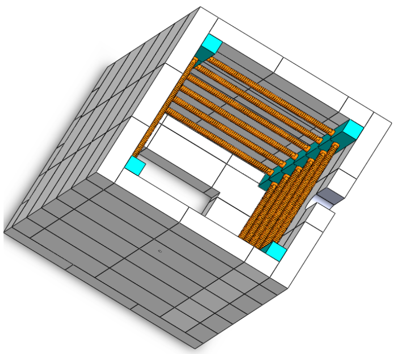

Figure 7 – Heating System

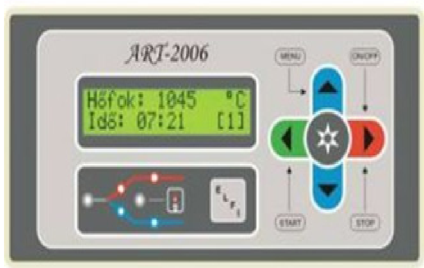

Figure 8 – Programmable controller, model ART 2006

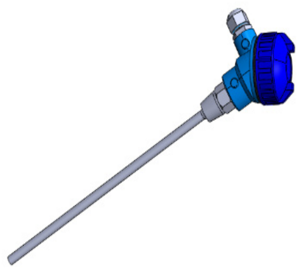

Figure 9 – Thermocouple type S

The combustion chamber insulation is made from three different types of heat–resistant materials to minimize heat loss. The three layers of insulation consist of:

— Ceramic fiber (25 mm thickness)
— Superwool Block 800 thermal insulation board (50 mm thickness)
— Basalt mineral wool board (50 mm thickness)

The non–asbestos refractory *ceramic fiber* blanket is designed to withstand high temperatures and is suitable for use in wall penetrations for chimneys, furnace thermal insulation, and separating the combustion chamber from the outer casing. It has a working temperature of 1260°C, a density of 128 kg/m³, and a thermal conductivity of 0.2 W/mK at 800°C. Its chemical composition consists of 46% $Al2O3$, 52% $SiO2$, and it has a thickness of 25 mm.

Superwool Plus Block 800 boards are made from Superwool Plus fibers, mineral fibers, and a small amount of organic binder. Due to their high fiber content, they are durable, lightweight, and resistant to thermal shocks. These boards also have a water–repellent treatment to prevent water absorption or absorption of cement–based binders. They exhibit good resistance to temperature cycles and have low thermal conductivity.

Basalt mineral wool boards, bonded with organic resin and hydrophobized throughout, are used for thermal, acoustic insulation, and fire protection of flat or slightly curved surfaces in industrial and thermal power plant equipment (boilers, furnaces, ovens, etc.). The basalt mineral wool has a thickness of 50 mm and a density of 100 kg/m³.

Figure 10 – Ceramic fibre

Figure 11 – Superwool Block 800 thermal insulation board

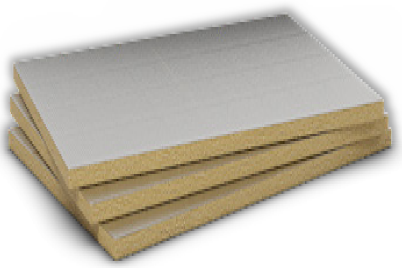

Figure 12 – Basalt mineral wool board

Given that the equipment will be placed in an enclosed space and the material used is poultry manure, the design team has decided to implement an alternative air purification system. This system is designed not only to eliminate the exhaust gases but also to remove undesirable odors, thus ensuring a cleaner and more pleasant working environment. This approach contributes to the efficiency of the pyrolysis process and reduces the impact on the surrounding environment.

The air purification system consists of:

1. Stage 1 – Coarse particle retention filter (metal filter)
2. Stage 2 – Retention filter for larger particles
3. Stage 3 – Retention filter for fine particles
4. Stage 4 – Odor retention/volatile substance filter

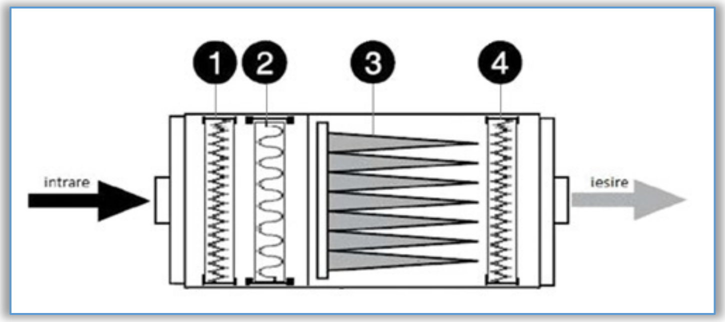

Figure 13 – The air purification system

4. DISCUSSION

The urgency for the development of pyrolysis technology, especially for the transformation of poultry waste into biochar and biofertilizers, is due to the increasing preference of eco–practices in agriculture as well as the effective management of the waste.

Efficiency of the Pyrolysis Process

Pyrolysis is an effective way of turning poultry waste into biochar and biofertilizers especially when it is done properly. The EP system has been constructed with the aim of increasing the yield of biochar and biofertilizers through control of a pyrolytic process. This task is carried out by keeping a controlled environment in which high temperatures up to 1150°C are to be maintained. This approach guarantees not only complete breakdown of poultry manure but also the result of nutrient–rich byproducts which are the most stable of biochar. Temperature control through programmable stages is possible with the developed equipment, the use of different materials should not be a problem and the implementation of the operation would be overall efficiency.

Environmental Impact of Pyrolysis Equipment

One of the main advantages of the pyrolysis process is the green impact it has. One feature of the EP pyrolysis system is the direct reduction of emissions by the use of an air cleaning system, which is functionally effective against hazardous gases and odors, and therefore, noncompliance with air quality standards. The whole is equipped with a multiple stage filter system that is composed of a rough particle filter and odor retention filter and hence can work in a cleaner and more sustainable manner, reducing air pollution risk normally associated with waste management practices.

Contribution to Sustainable Agriculture

The pyrolysis process not just a sustainable manner for the disposal of waste materials but also the practice supports the orchard and vineyard fertilization on a sustainable basis. The biofertilizers having key nutrients including phosphorous which are produced through the environmental protection system are the main components for the healthy vegetation growth especially in the nutrient–poor soils.

Economic and Social Implications

The need for the capital for the acquisition of pyrolysis devices can be daunting in the first place. Still the economic profits that will come out of pyrolysis processes will be much bigger than the costs. By transforming poultry manure into valuable bioproducts, farmers not to buy chemically produced fertilizers that are very expensive and avoid environmental degradation.

5. CONCLUSIONS

In conclusion, the pyrolysis equipment designed for processing poultry manure offers a sustainable and efficient solution for waste management in poultry farming. The system integrates advanced features, such as precise temperature control, air purification, and robust insulation, which contribute to the optimization of the pyrolysis process. By transforming poultry manure into valuable byproducts like biochar, biofuels, and phosphorus–rich biofertilizers, the equipment not only addresses waste disposal challenges but also supports more sustainable agricultural practices. Furthermore, the modular design, including safety mechanisms like automatic fuses and overload protection, ensures the system's safe and reliable operation. The air purification system enhances the environmental performance by reducing harmful emissions and unpleasant odors, making it suitable for use in enclosed spaces. Overall, this pyrolysis unit represents a significant step toward achieving a circular economy in the agricultural sector, promoting resource recovery and minimizing environmental impact

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