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Development of an Eco-Friendly Egg Tray Molding Machine for Paper Waste Reduction at Politeknik Negeri Semarang

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Abstract: The increasing consumption of paper at Politeknik Negeri Semarang has led to a significant rise in paper waste that has not been managed optimally. This condition presents a significant issue, characterized by waste accumulation and the underutilization of recyclable paper as a value-added product. Although various paper-recycling technologies have been developed, most existing systems operate on an industrial scale, making them unsuitable for vocational education settings that require compact, energy-efficient, and user-friendly equipment. This gap highlights the need for a practical, small-scale recycling technology that can be effectively implemented within the campus environment. This research aimed to design and construct a Paper Egg Tray Machine as a small-scale waste-paper processing solution capable of converting paper waste into environmentally friendly packaging products. The research method includes needs assessment, mechanical and electrical design, fabrication, and performance testing. The machine was designed with dimensions of 1400 × 990 × 1400 mm, utilizing a 12 V battery system and a 220 V, 150 W dynamo motor with a power-transfer mechanism based on an electric winch. The pulp-processing system uses a 200 mm centrifugal blade agitator. The results showed that the machine successfully processes waste paper into homogeneous pulp and forms it into recycled egg trays with consistent shape and structural stability. The produced trays meet basic functional requirements as protective packaging and demonstrate potential for small-scale production. In conclusion, the Paper Egg Tray Machine contributes to the development of simple, efficient, and environmentally friendly waste-processing technology suitable for vocational education while offering broader opportunities for implementation in small recycling-based enterprises.

Keywords: Egg tray, Machine design, Paper recycling, Paper waste

1. Introduction

Paper consumption in higher education institutions continues to rise annually, primarily due to academic and administrative activities such as printing assignments, laboratory reports, official documents, and office operations [1]. A similar pattern is observed at Politeknik Negeri Semarang, where the increasing use of paper directly contributes to a growing volume of paper waste. Without an integrated waste management system, this accumulation poses significant environmental challenges, including increased solid waste generation and reduced landfill capacity [2]. Therefore, effective strategies for reusing and repurposing paper waste are necessary to mitigate environmental impacts while enhancing resource efficiency.

Previous studies highlight that paper waste is one of the most recyclable materials due to its cellulose fiber structure, which can be reprocessed into new products [3]. Recycling technologies generally involve pulping, fiber disintegration, molding, and drying processes. Among the recycled products, egg trays made from paper pulp have gained substantial popularity due to their biodegradability, lightweight nature, and environmental friendliness, serving as an alternative to plastic-based packaging [4]. Furthermore, the poultry sector continues to demand durable and cost-effective egg packaging, contributing to the growing relevance of recycled egg trays [5].

Despite their advantages, most commercial paper-recycling and egg-tray molding machines are designed for industrial-scale production. These systems typically require large operational space, high electricity consumption, and substantial investment costs. Such characteristics make them unsuitable for educational environments or small enterprises. Moreover, research on small-scale, appropriate technology for paper-waste processing within vocational education settings remains limited [6]. This situation indicates a clear gap between the need for accessible, small-scale recycling machinery and the availability of equipment that supports practical learning in vocational institutions.

Addressing this gap requires the development of a compact, user-friendly recycling machine that can be easily integrated into campus environments. A Paper Egg Tray Machine designed through an appropriate technology approach not only supports paper waste reduction but also provides hands-on learning opportunities for students in mechanical design, manufacturing technology, and sustainable engineering practices. Such a machine is expected to operate with minimal energy requirements, simple control mechanisms, and ease of maintenance.

Based on the background and gap analysis, the objective of this research is to design and develop a Paper Egg Tray Machine suitable for small-scale applications in vocational education. The study aims to develop a machine capable of processing paper waste into homogeneous pulp and molding it into functional egg trays, thereby contributing to sustainable waste management solutions and promoting environmentally responsible practices within educational institutions.

2. Methods

2.1 Machine Design

The machine was designed with an emphasis on structural rigidity, compactness, and suitability for campus-scale applications. The main frame was constructed using hollow steel to ensure stability while maintaining a lightweight structure. The prototype dimensions—1400 mm × 990 mm × 1400 mm—were selected to provide sufficient working space without occupying excessive laboratory area. The design process included conceptual modeling, dimensional planning, and mechanical layout optimization (Figure 1).

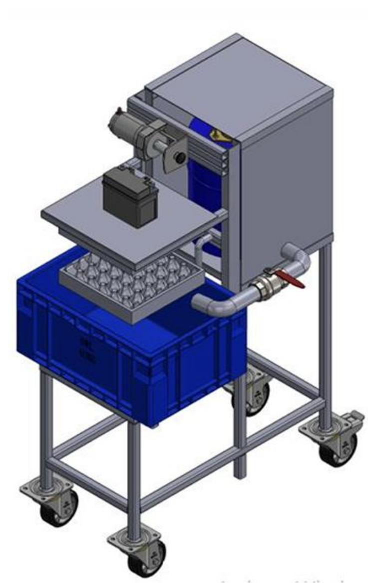

Figure 1. *Three-dimensional design model of the Paper Egg Tray Machine prototype, featuring a compact steel frame structure, pulping tank, vacuum-assisted forming mold, electric-winch lifting mechanism, and caster wheels for mobility.*

2.2 Power System and Transmission

A dual-source power configuration was implemented to increase operational flexibility, including a 12 V battery for portable and off-grid operation and a 220 V, 150 W dynamo motor for stable laboratory use. Power transmission to the lifting and forming mechanism was achieved using an electric winch, functioning as a pulley-based system to raise and lower the mold during forming.

2.3 Pulping Procedure

Paper waste was sorted, soaked, and processed using a centrifugal blade agitator with a 200 mm diameter. The agitator was designed to efficiently disintegrate paper fibers, producing homogeneous pulp. Parameters considered included blade geometry, rotational speed, and processing time.

2.4 Forming and Molding

Homogeneous pulp was transferred into the molding chamber using the winch-lifting mechanism. The forming process employed a vacuum-assisted principle, allowing water to be removed through suction while enabling pulp fibers to adhere uniformly to the mold surface. Mold patterns were adjusted to ensure a consistent tray shape and wall thickness.

2.5 Drying Process

Due to laboratory-scale constraints, drying was performed manually using natural sunlight. Although industrial systems commonly use heated multi-layer drying lines, manual drying was sufficient for evaluating prototype performance and structural characteristics of the trays.

2.6 Evaluation and Testing

Machine performance was assessed through operational stability during continuous operation, quality of pulp homogeneity, uniformity of molded tray geometry, drying duration, and mechanical strength of finished trays. Observations were recorded through visual inspection, manual measurements, and process documentation.

3. Results and Discussion

The prototype development resulted in a compact machine measuring 1400 × 990 × 1400 mm, which was successfully constructed using a hollow steel frame that provided adequate structural stability (Figure 2). The chosen materials and frame geometry ensured that the machine remained rigid during pulping, forming, and lifting operations, which aligns with recommendations for the design of small manufacturing and recycling equipment [7]. This confirms that the design specifications were appropriate for a small-scale, campus-based recycling system.

Figure 2. *Prototype of the Paper Egg Tray Machine in operational condition, featuring the dual-power system, vacuum-assisted forming mold, and pulp collection container, assembled for functional testing in the campus environment.*

Testing of the dual-power system demonstrated that both the 12 V battery and the 220 V–150 W dynamo motor operated reliably under typical forming loads. Hybrid or dual-power approaches have been shown to improve flexibility and ensure machine functionality in environments with fluctuating power availability [8]. The electric winch effectively lifted and lowered the mold assembly, allowing for consistent control during the forming process. This configuration provided operational reliability comparable to that of other small-scale molding and lifting mechanisms [9]

The centrifugal blade agitator, with a 200 mm diameter, successfully produced a homogeneous pulp suitable for molding. Previous studies highlight that centrifugal pulping results in better fiber dispersion, higher uniformity, and improved suitability for molded-pulp applications compared to manual agitation [10]. The uniform fiber consistency obtained in this prototype further supports the effectiveness of centrifugal mixing, particularly for small-scale production settings [11].

The forming process using a vacuum-assisted mold produced egg trays with a consistent shape and minimal surface defects [12]. Vacuum-assisted forming is known to improve water extraction and enhance fiber adhesion during the molding stage [13]. The efficient suction mechanism in this prototype ensured uniform adhesion across mold contours, suggesting that the pore distribution and mold geometry were appropriate for prototype-scale production.

Drying tests showed that although the trays could be dried using sunlight or ambient air, the drying time was significantly longer than in industrial-scale machines equipped with multi-layer heated dryers. This finding is consistent with reports that natural drying is slower and less controlled than thermal drying systems commonly used in pulp-molding industries [14]. However, the manual drying approach used in this study remains feasible for prototype validation and educational demonstration settings.

From a broader sustainability perspective, the prototype demonstrates the potential for repurposing campus-generated paper waste into value-added products. Converting paper waste into molded-pulp egg trays supports circular-economy practices by reducing waste and creating renewable packaging materials [15]. Prior studies also indicate that molded-pulp egg tray production holds strong economic prospects for small enterprises and community-scale projects, reinforcing its relevance for campus innovation and student entrepreneurship [16].

Despite the success of the prototype, several challenges were identified, including the need for designated drying space, maintaining optimal pulp consistency, and managing energy consumption during the forming process. These constraints are similarly reported in earlier research on the development of small-scale molded-pulp equipment [17]. Future improvements should therefore include integrating automated drying modules, optimizing pulp formulation, and conducting cost–benefit analyses to assess scalability for campus-level production or student-run business initiatives.

4. Conclusion

This study successfully designed and developed a functional prototype of the Paper Egg Tray Machine as an applied solution for paper-waste management at Politeknik Negeri Semarang. The prototype demonstrated effective performance in converting waste paper into homogeneous pulp and forming it into structurally consistent egg trays using a vacuum-assisted molding system. The machine's compact dimensions, dual-power configuration, and stable steel-frame construction validate its feasibility for small-scale recycling applications within a campus environment. Although the current drying method remains manual and relatively slow, the overall process flow from pulping to forming proves technically viable for demonstration and educational purposes. The results indicate that the system has potential for further development into a small to medium-scale production unit suitable for vocational training, entrepreneurship programs, or community-based recycling initiatives. Beyond its technical functionality, the prototype supports sustainability efforts by reducing paper waste while generating value-added products. The machine also enhances learning opportunities in engineering design, manufacturing, and green technology. Future improvements should include the integration of an automated drying subsystem, refinement of pulp formulation parameters, and a more comprehensive evaluation of energy efficiency and production costs to strengthen scalability and long-term implementation.

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