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Engineering a Circular Economy: Designing a Machine to Transform Low-Value Plastic Waste into Multipurpose Board

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Abstract: *This study conceptualizes the utilization of plastic waste into multipurpose boards through the principles of the circular economy. The research aims to reduce the volume of plastic waste that negatively impacts the environment and to create new economic value by transforming waste into valuable products, while simultaneously conserving natural resources by reducing the use of virgin raw materials. The method employed involves creative recycling or upcycling processes that integrate the principles of Reduce, Reuse, and Recycle. The process includes collecting, sorting, shredding, and molding processed plastics into new products such as durable multipurpose boards, thereby reducing waste and generating new economic value. The results demonstrate the creation of high-value products, such as boards that can be used to make items like storage boxes, reading tables, and even paving blocks, alongside associated economic and environmental benefits. The economic benefits include the creation of new job opportunities in the recycling sector, while the environmental benefits encompass the reduction of plastic waste and the conservation of natural resources by decreasing dependence on new raw materials.*

Keywords: **Circular economy, plastic recycling, plastic waste, multipurpose board, economic value, waste processing machinery**

1. INTRODUCTION

Waste management has become a major environmental and social challenge in many regions due to rapid population growth and urbanization [1]. One of the most difficult types of waste to manage is low-value plastic (Low-Value Plastic, LVP). This category of waste, such as single-use flexible packaging (sachets and plastic bags), is difficult to recycle through conventional processes because its processing costs tend to exceed its economic value [2, 3]. As a result, LVP is often poorly managed and becomes a primary source of environmental pollution.

The urgency of the LVP problem lies in three main aspects: volume, recycling rate, and environmental impact. High plastic consumption, combined with low public awareness of waste segregation, has resulted in a large accumulation of LVP in the environment. In Indonesia, the plastic recycling rate is only around 10%, meaning that the majority of waste ends up in landfills or pollutes the environment [4]. The impact is significant because this type of plastic is highly resistant to degradation, causing water, air, and soil pollution, and posing potential health hazards. Therefore, innovative and sustainable solutions are needed to convert this waste into valuable material.

Addressing LVP requires an approach that integrates technical, economic, and environmental dimensions through the adoption of a circular economy. A circular economy aims to preserve the value of products and materials for as long as possible, replacing the linear "take-make-dispose" model with a "closed-loop" system through reuse, repair, and recycling [4, 5].

This study proposes a solution by upgrading low-value plastic waste through creative recycling (upcycling) into multipurpose boards. The process involves cleaning, shredding, heating, and pressing (molding) pre-processed plastic. These boards can serve as alternative building materials to replace wood in furniture, wall partitions, or lightweight construction applications, thereby conserving natural resources.

Several previous studies related to the circular economy have demonstrated the potential to convert low-value plastic into high-value products. For example, Haba et al. [7] examined various strategies and applications for recycling plastic waste, with particular focus on sustainable construction solutions, and evaluated the strengths and limitations of these approaches. In this context, recycled plastic waste can be used as filler material to replace non-renewable natural resources, and studies have shown that its addition can improve various composite properties, including thermal and acoustic insulation.

Soemadijo et al. [8] mapped available options for addressing low-value plastic waste in Indonesia and assessed their readiness across technological, environmental, social, and economic dimensions. Three feasible options identified were conversion into plastic lumber, production of refuse-derived fuel (RDF), and conversion into plastic products—all of which are supported by mature technologies and local availability.

Bucknall [9] investigated strategies to prevent material resource loss and environmental degradation as part of a circular plastics economy, which aims to retain plastics at their highest value for as long as possible while simultaneously enhancing economic outcomes and preventing harmful environmental impacts. This has driven rapid changes in policies and regulations worldwide to address these environmental challenges. Achieving a circular economy requires not only innovative technical development but also significant economic investment, shifts in business practices, and substantial changes in social behavior.

Although previous studies have validated the potential of LVP as an alternative raw material and identified mature technological options (such as converting LVP into plastic lumber), there remain significant gaps in the literature that need to be addressed. First, a gap in engineering and manufacturing design persists: most studies focus on conceptual and material feasibility but do not discuss in detail the engineering and specific design of processing machines that can be mass-applied at the community or local level, such as plastic sheet press machines. Second, a gap exists in process analysis models: there is no systematic analysis linking core operating parameters (temperature, pressure, time) with machine design and final product quality using simple mathematical models as tools for optimization and quality control.

Based on these gaps, the main objectives of this study are: to design and engineer a plastic sheet press machine suitable for converting low-value plastic waste into multipurpose boards; to analyze the conversion process using simple mathematical calculations (Heating and Compaction Models) to support process optimization; and to provide justification and examples of high-value applications for the resulting boards.

Based on these considerations, this study offers scientific novelty by integrating engineering machine design (processing equipment) with mathematical process models $(Q = m \cdot c \cdot \Delta T$ and $F = P \times A)$, explicitly aimed at supporting mass production across multiple locations and accelerating circular economy implementation at the grassroots level. Thus, the implications of this research are extensive: from an environmental standpoint, the study directly contributes to reducing the volume of plastic waste that pollutes the environment and conserving natural resources by lowering dependence on virgin materials; from an economic and social perspective, it promotes the creation of new economic value from previously worthless waste, generates new employment opportunities in the recycling sector, and strengthens local economies through the provision of replicable production tools; and from a technical perspective, it provides a justified technical foundation (through design and mathematical modeling) for the development of efficient recycling machines that can be mass-produced.

2. Preliminaries

2.1. Low-Value Plastic Waste

Low-value plastic (Low-Value Plastic, LVP) is defined as a type of plastic that has low market demand, low commercial value, or is difficult to recycle economically [8, 9]. This category includes materials that pose technical challenges in processing, such as multilayer sachets, plastic bags, and various types of flexible plastics. These processing difficulties are often caused by the diversity of polymer types, contamination, or complex material structures, making LVP a problematic waste stream to manage.

The volume of LVP in the environment is very large and represents an urgent issue [12]. This is driven by Indonesia's low plastic recycling rate and limited public awareness of waste segregation, resulting in most LVP ending up in landfills or leaking into the environment. The accumulation of LVP causes serious pollution because these materials are resistant to natural degradation, hence requiring innovative processing solutions.

The value of LVP can be enhanced through various approaches, such as creative recycling into handicrafts, use in the construction industry (for example, mixed with asphalt for paving blocks or roads), or conversion into energy sources [13]. In the context of this study, LVP is upgraded by processing it through recycling stages that include cleaning, shredding, heating, and pressing, resulting in strong and useful composite boards that function as an alternative to wood.

2.2. Circular Economy

The Circular Economy is an economic model that stands in contrast to the traditional linear model of "take-make-dispose." It aims to promote sustainable growth by preserving the value of products, materials, and resources for as long as possible [14]. Its primary goals are to minimize waste, reduce natural resource consumption, and mitigate environmental degradation by creating a closed-loop system [6]. This model is achieved through key strategies such as reuse, repair, recycling, and the renewal of products and materials.

Business models within the Circular Economy can be categorized into several types, including circular material use, sharing models, product-as-a-service systems, product life extension, and resource recovery. Its implementation is prioritized across various sectors, including food and beverages, textiles, construction, trade (particularly plastics), and electrical and electronic equipment. In the context of plastic waste, the Circular Economy encourages efforts to maintain plastics at their highest possible value for as long as feasible to prevent harmful environmental impacts [15].

The implementation of the Circular Economy relies heavily on community empowerment and changes in social behavior. Such empowerment aims to enhance economic well-being and environmental quality through active community participation. This is achieved by providing training and assistance in processing waste into value-added products, promoting circular-based local entrepreneurship, and increasing awareness of independent environmental management—ultimately fostering creative village models and strengthening local economies sustainably.

2.3. Environmental Sustainability

Environmental sustainability is the ability to maintain the planet's ecological balance, preserve natural resources, and protect the environment [16]. This concept emphasizes responsible decision-making to ensure that the planet can support the lives of current and future generations without compromising future needs. It involves conscious efforts to reduce pollution, conserve energy and water, and minimize waste, particularly plastics that are difficult to decompose.

Efforts to maintain environmental sustainability are a shared responsibility that requires active participation from governments, communities, businesses, and individuals. Governments play a crucial role in establishing supportive policies, while communities and individuals are responsible for simple actions such as reducing plastic use, disposing of waste properly, and conserving water. The main pillars of sustainability include nature conservation (biodiversity preservation), natural resource management (using recycled products), and active participation (supporting renewable energy).

In the context of this study, recycling plastic waste into multipurpose boards serves as a concrete manifestation of environmental sustainability efforts. Recycling can reduce waste volume, conserve natural resources, and prevent pollution by transforming contaminating waste into useful products. Programs of this kind—supported by consistent policies—are essential for reducing waste, conserving resources, and sustainably preserving the environment for the future.

3. Material and Methods

3.1. Materials

The materials used in this study are divided into raw materials for the final product and components required for designing the plastic sheet press machine.

3.1.1. Board Raw Materials

The primary raw material is low-value plastic waste (Low-Value Plastic, LVP). The types of plastics targeted include Polypropylene (PP), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), and Multi-Layer Packaging (MLP). These materials are collected from waste sources and mixed. In addition to plastics, additives such as wood powder or sawdust may be added as fillers and binders to enhance the structural quality of the composite board.

3.1.2. Machine Design Components (Sheet Press)

Several main components are used to construct the plastic sheet press machine. The structural frame is built using structural steel materials, such as WF400 steel beams, to ensure rigidity and resistance to high compressive forces. The pressing system is operated using a hydraulic system consisting of a cylinder, hydraulic pump, and control valves. Meanwhile, the heating system (hot press) functions by circulating heat-resistant oil through thick steel pressing plates. The overall heating and pressing operations are controlled through an electrical control panel.

3.2. Methods

This research method is structured into four main phases: Machine Design, Raw Material Preparation, Conversion Process (Molding), and Result Analysis.

3.2.1. Machine Design and Needs Analysis

This phase focuses on the engineering of the plastic sheet press machine. It begins with a needs analysis to determine operational specifications, such as the type of plastic to be processed, targeted production capacity, and the desired output sheet size. Based on these requirements, a machine design concept is developed, taking into consideration manufacturing feasibility, ergonomics, and work safety.

The technical steps involve detailed engineering calculations, including determining the strength of the machine frame, analyzing the hydraulic and pneumatic systems, and calculating the heat resistance of the oil used. In addition, the mold is designed to withstand high temperatures and pressure, and the mold material is selected to ensure it does not adhere to the melted plastic.

3.2.2. Raw Material Preparation

This phase prepares plastic waste into material ready for molding. The preparation workflow includes:

a. Collection and Sorting: Plastic waste is collected and sorted by polymer type and color to ensure consistency in the final product quality.
b. Shredding and Washing: The sorted plastic is washed to remove contaminants and shredded into small flakes to facilitate melting.
c. Drying: The plastic flakes are dried optimally to prevent moisture-related issues during the hot-pressing process.
d. Mixing: The dried plastic flakes are mixed according to predetermined formulation ratios to achieve specific material properties (for example, more flexible or more rigid boards).

3.2.3. Board Conversion Process (Hot Press Molding)

This process is the core phase in which the multipurpose boards are produced. The process includes:

a. Machine Heating: The hot press machine is heated until it reaches the required operational temperature (minimum 180°C).
b. Hot Pressing: The mixed raw material is weighed and placed into a lubricated mold tray. The mold is then inserted into the hot press machine and subjected to hydraulic pressure. The heating and pressing process is carried out for a specified cycle duration to ensure the plastic melts and compacts evenly.
c. Cooling and Finishing: After the cycle time is completed, the pressure is released and the mold is removed. The board is cooled (cold press) to stabilize its structure. Once cooled, the board is cut to trim its edges and adjust its dimensions, making it ready for use or commercial distribution.

3.2.4. Result Analysis

The final phase involves evaluation and technical justification. A simple mathematical model (Heating and Compaction Model) is applied to analyze and optimize key process parameters (temperature, pressure, and time) to predict dimensional consistency and sheet strength. Additionally, the final product is tested to verify its mechanical and dimensional properties, and the results are discussed in the context of circular economy implications

The steps described above can be summarized as a workflow for processing low-value plastic waste into boards, as presented in Figure 1.

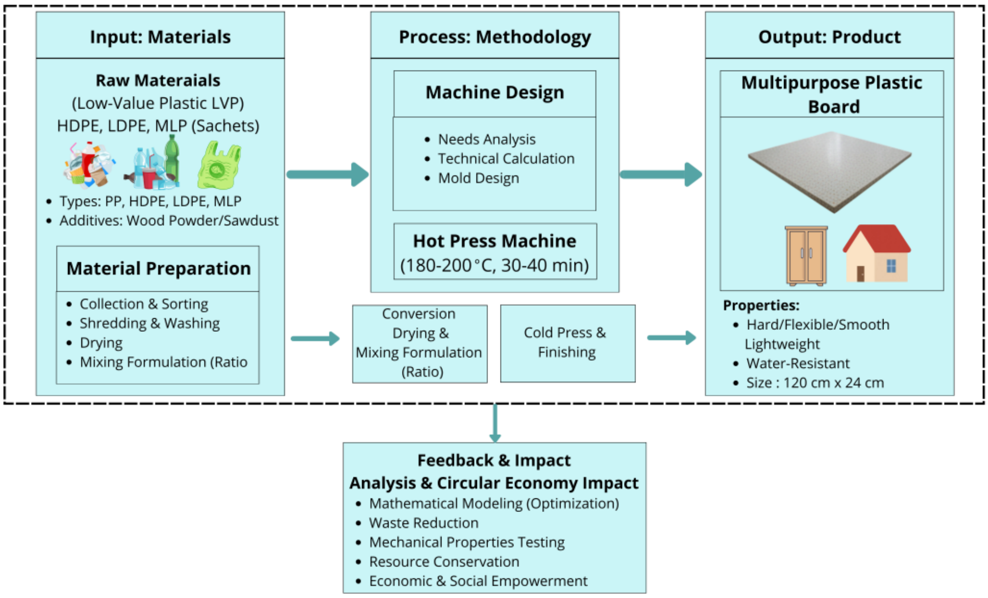

Figure 1. Workflow framework for processing low-value plastic waste into multipurpose plastic boards

4. Results and Discussion

4.1. Mathematical Model

The mathematical model for the plastic sheet press machine focuses on the relationship between input variables (heat and pressure) and output (quality of the plastic sheet produced), taking into account parameters such as heat transfer rate, temperature, applied pressure, and processing time. This mathematical model serves as a predictive and control tool to optimize energy efficiency, cycle time, and the quality of the final product (multipurpose boards) produced by the sheet press machine. The model emphasizes thermal dynamics that influence the viscosity of molten plastic and the mechanical forces required for compaction.

4.1.1. Heating Model: Energy and Cycle Time Optimization

The Heating Model is essential because temperature (T) directly determines the viscosity of plastic. A successful molding process requires the plastic to reach a specific melting temperature $(180-200^{\circ}C)$.

a. Heat Transfer Equation (Q)

This equation calculates the total thermal energy required by the heating system to melt the mass of plastic placed in the mold

$$Q = m \cdot c \cdot \Delta T, \tag{1}$$

where:

- Q : Heat transferred (Joule or "Watt"·"second").
- m : Mass of plastic processed (kg).
- c : Specific heat capacity of the plastic (varies by polymer, $J/(\text{kg} \cdot K)$).
- ΔT : Desired remperature change (T_final-T_initial, Kelvin or Celcius).

Application in the Machine:

- Heating Capacity Design: Knowing the mass of plastic (m) processed per cycle and the required ΔT allows this equation to serve as the basis for calculating the minimum power (Watt) needed for the machine's oil heating system.
- Temperature Control of the Mixture: This model ensures that the plastic mixture (e.g., HDPE, PP, MLP with different specific heat capacities c) receives sufficient energy to melt uniformly before pressure is applied.

b. Heating Rate Model (dT / dt)

The rate of temperature change over time is crucial for determining the soaking time required during hot pressing

$$\frac{dT}{dt} = \frac{P_{heater}}{mc}, \tag{2}$$

where:

- $\frac{dT}{dt}$: Rate of temperature change (°C/Second).
- P_{heater} : Power generated by the heating system (hot press) (Watt).

Application in the machine:

- Cycle Time Optimization: This model allows prediction of how long (t) it takes for plastic mass (m) to reach the target melting temperature (T_{melt}), depending on heater power (P_{heater}). This minimizes cycle time and increases productivity.
- Temperature Maintenance: In continuous operation, this model helps maintain the plate temperature within an optimal range and compensates for heat loss to the environment.

4.1.2. Compaction Model: Mechanical Force and Rheology Analysis

The Compaction Model determines the force (F) required from the hydraulic system to compress the molten plastic and ensure it fills the entire mold volume.

a. Pressure-Force Equation

This equation relates the output force from the hydraulic jack (F) to the specific pressure (P_{pressure}) applied to the mold surface area (A):

$$F = P_{\text{pressure}} \times A \tag{3}$$

where:

- F : Force generated by the hydraulic system (Newton or ton)
- P_{pressure} : Pressure needed for mold filling and compaction (Pascal or N / m^2).
- A : Mold surface area (m^2).

Application in the machine:

- Hydraulic System Design: This equation is used directly to determine the specifications of the hydraulic cylinder (cylinder diameter, pump pressure) needed to generate the force (F) capable of sustaining the required compaction pressure (P_{pressure}).

- Machine Frame Justification: The maximum calculated force (F) becomes a critical parameter for stress calculations and material selection for the machine frame (WF400 steel), ensuring structural stability and preventing deformation during pressing.

b. Rheological Correlation (Viscosity and Pressure)
The quality of the board depends heavily on the ability of molten plastic to flow and fill the mold, governed by viscosity

- Viscosity (η): The required pressure (P_{pressure}) is inversely proportional to molten viscosity. A lower viscosity—achieved at higher temperature (T)—requires lower pressure for mold filling. If T is too low, η becomes high, requiring much greater pressure.
- Elastic Modulus: After compaction, the applied force must maintain the board's structure during cooling. The model ensures sufficient pressure to achieve uniform density and desired mechanical properties (e.g., high flexural modulus) without excess flash material.

Overall, this Mathematical Model provides an industrial foundation that allows machine designers to move from empirical estimation to data-driven engineering, ensuring that plastic sheet press machines can be mass-produced with optimal performance and consistent product quality.

4.2. Design of the Plastic Sheet Press Machine

The design of the plastic sheet press machine is the result of technical calculations and needs analysis aimed at creating a robust, efficient, and mass-producible tool capable of processing Low-Value Plastic (LVP) into multipurpose boards. The design focuses on four main aspects: structural frame, driving system (hydraulic), heating system (hot press), and control system. The layout design of the plastic board processing machine is shown in Figure 2.

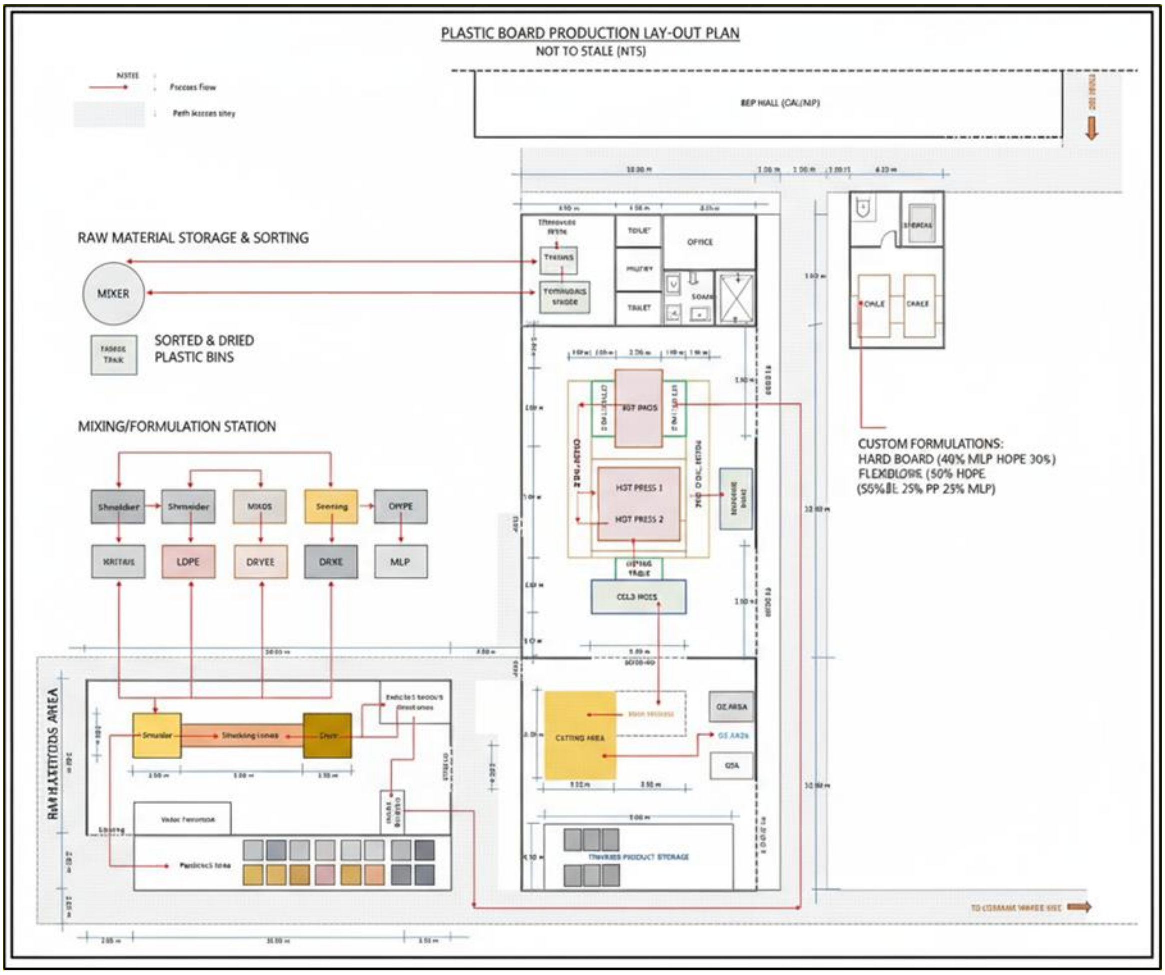

Figure 2. Layout design of the plastic board production machine

4.2.1. Structural Frame and Main Components

The machine frame is designed to withstand very high compressive forces without experiencing permanent deformation.

1) Main Frame: Constructed using heavy-profile steel materials such as WF400 steel beams as the primary support structure. This material selection is based on tensile and compressive stress calculations to ensure structural stability during the pressing process.
2) Pressing Plate: The component that comes into direct contact with the mold. This plate is made of thick steel (recommended thickness: 10 cm) to ensure even distribution of pressure and heat across the entire mold surface.
3) Precision Alignment Components: Guide pins and guide bushings are used to ensure the pressing plate moves vertically with high precision. This is crucial for producing boards with consistent thickness across all sides.

4.2.2. Driving System (Hydraulic System)

A hydraulic system is chosen due to its ability to generate high force (tons) and high pressure (Pascals), which are required to compact molten plastic with high viscosity.

1) Hydraulic Components: Consist of a high-capacity hydraulic cylinder as the actuator, a hydraulic pump to generate fluid flow, and a fluid reservoir to contain hydraulic oil.
2) Force Calculation: Hydraulic force calculations are based on the Compaction Model $(F = P_{\text{pressure}} \times A)$. The total force (F) required is computed to ensure sufficient

pressure (P_{pressure}) can be applied across the mold area (A). This determines the cylinder size and pump working pressure.

3) Control Valves: Used to regulate oil flow direction into the cylinder, enabling upward and downward movement of the pressing plate, as well as controlling pressure holding time.

4.2.3. Heating System (Hot Press)

The heating system is designed to supply and maintain the optimal melting temperature $(180-200^{\circ}C)$ in the mold during pressing.

1) Special Heating Oil: The machine uses heat-resistant oil circulated through internal channels within the steel pressing plates. This oil functions as an efficient heat transfer medium capable of reaching high temperatures without degrading.
2) Oil Heater Unit: A high-power oil heating machine (estimated around 30,000 Watts) is used, calculated based on the Heating Rate Model $(dT/dt = P_{\text{heater}}/mc)$ to ensure fast and efficient heating.
3) Temperature Control System: Equipped with thermocouples and a precise digital temperature controller to maintain plate temperature stability within the required range for different plastic types (e.g., HDPE or MLP).

4.2.4. Design and Manufacturing Techniques

The design process follows a systematic workflow to ensure effectiveness and safety.

1) Concept Analysis: A comparative study is conducted between hydraulic systems (selected for superior force output) and alternatives such as pneumatic or manual mechanical systems, considering cost, durability, and labor requirements.
2) Mold Design: Molds are designed with high precision according to the required product shape. Mold materials must have good thermal conductivity and withstand repeated pressure. Teflon sheets may be used to line the mold tray to prevent plastic adhesion.
3) Safety and Ergonomics: The design includes essential safety features such as protective covers and emergency stop buttons. Ergonomic aspects such as hydraulic lever height and working posture are also considered.

4.3. Process of Converting Plastic Waste into Boards

The conversion of low-value plastic waste (LVP) into multipurpose boards is carried out using a plastic sheet press machine and follows a standardized series of operational steps to ensure final product quality. This process consists of raw material preparation and the core pressing process.

4.3.1. Material and Mold Preparation

The process begins after LVP raw materials have undergone initial preparation (sorting, shredding, washing, drying, and mixing).

1) Specific Sorting and Mixing Formulation: Plastic waste is sorted by material type (PP, LDPE, HDPE, MLP). It is then mixed according to formulations designed to achieve the desired board characteristics. Example formulations include:
   a. Rigid Board: 40% MLP, 30% HDPE, 30% PP (clear).
   b. Flexible Board: 50% HDPE, 25% PP (clear), 25% MLP.
   c. Smooth and More Flexible Board: 75% HDPE, 25% PP (clear).
2) Material Weighing: Shredded and mixed plastic is weighed accurately. For a single board mold measuring $130\,\text{cm} \times 250\,\text{cm}$ with thickness variations (e.g., 10 mm, 12 mm, or 16 mm), approximately 3.2 kg of raw material is required.

3) Mold Preparation: The mold tray and its boundaries are coated evenly with oil. Using oil or Teflon sheets is essential to prevent molten plastic from sticking to the mold and to ensure the resulting board has a smooth, clean surface.

4.3.2. Hot Pressing Process (Hot Press)

This is the core phase in which heat and pressure transform shredded plastic into solid sheets.

1) Machine Heating: The hot press machine is activated. The circulating special heating oil warms the steel plates until they reach the optimal operating temperature $(180-200^{\circ}C)$. The machine is allowed to reach stable temperature to ensure consistent melting.
2) Mold Filling: The weighed plastic material is poured into the mold tray, with more material placed at the center. This strategy ensures full mold coverage once the plastic melts and spreads under pressure.
3) Pressurized Hot Pressing: The mold is closed and carefully inserted into the heated press. The hydraulic lever is pumped to apply strong pressure to the mold. The heating and pressing cycle typically last 30–45 minutes.
4) Production Capacity: With optimal design, the machine can accommodate multiple molds in one pressing cycle (e.g., up to 5 molds per press).

4.3.3. Completion dan Finishing

After the hot compaction process is completed, the boards require cooling and final adjustments.

1) Pressure Release: Once the pressing duration is reached (30 minutes), the hydraulic lever is rotated to release the pressure on the mold.
2) Cooling (Cold Press): The mold containing the hot board is removed. The board is then cooled using a cold press machine or left to cool naturally. Stable cooling is crucial to stabilize the sheet and lock in the final board dimensions. This cooling process can take a long time (for example, approximately 8 hours are required to stabilize 100 boards).
3) Cutting and Final Dimensions: Once cooled, the multipurpose board is ready to be cut using a cutting machine. Cutting is performed to trim the board edges and adjust its size to commercial standards, such as $120\,\text{cm} \times 240\,\text{cm}$.

4.4. Results and Applications

The main outcome of the plastic sheet press machine engineering process and the conversion method is the creation of multipurpose boards with high economic value and superior durability from low-value plastic waste. These boards serve as alternative building and furniture materials that can substitute for wood.

4.4.1. Product Characteristics

The boards produced through hot pressing exhibit varying characteristics depending on the raw material formulation (HDPE, PP, MLP) and processing parameters (temperature and pressure).

1) Rigid Boards: Produced from formulations with a higher percentage of MLP (Multi-Layer Packaging), resulting in high stiffness and compressive strength. These boards are ideal for structural applications requiring high durability.
2) Flexible Boards: Produced from formulations dominated by HDPE (High-Density Polyethylene), resulting in boards that are more elastic, impact-resistant, smooth-surfaced, and more flexible.

3) General Quality: These composite plastic boards are generally strong, durable, lightweight, and most importantly, water-resistant and weather-resistant, making them suitable for both indoor and outdoor applications.

4.4.2. Applications in Construction and Interior Design

These multipurpose plastic boards have great potential as alternative construction materials, reducing dependence on wood and other conventional materials.

1) Wall Partitions: The boards can be molded into solid, strong sheets suitable for interior or exterior wall partitions. Their lightweight and waterproof properties make them ideal for wall or ceiling panels.
2) Roofing: Boards can be formed into roofing panels—either corrugated or flat—similar to PVC (uPVC) or polycarbonate roofing materials. Their lightweight and weather-resistant characteristics facilitate easy installation.
3) Simple Construction: These boards can be used as basic materials for building simple houses, waterproof wall cladding, and exterior decorative panels.

4.4.3. Applications in Furniture and Other Products

The applications of these boards extend broadly across the furniture and product design industries, leveraging their durability and moisture-resistant properties.

1) Furniture: The boards can be used to manufacture various furniture items such as shelves, cabinets, tables, chairs, and kitchen sets.
   a. Tables: They can be transformed into study tables, sturdy folding tables, multipurpose/guest tables, or modular table components.
   b. Chairs: The material is suitable for outdoor garden chairs due to its resistance to sunlight and water, as well as indoor uses such as café chairs or study chairs.
2) Other Products: Beyond furniture, the boards can be processed into garden components (pots or polybags) or products such as storage boxes and paving blocks—demonstrating that low-value waste can be transformed into higher-value goods.

The creation of these high-value products directly delivers economic benefits (job creation) and environmental benefits (reduction of plastic waste and conservation of natural resources). Examples of multipurpose board products with high economic value can be seen in Figure 3.

a. Cabinet b. Door c. Trash bin

d. Table & Chairs e. Roof Panel f. Chart

Figure 3. Processed multipurpose plastic boards transformed into high-value furniture and other products

4.5. Discussion

4.5.1. Technical Justification and Process Optimization

Mathematical model as a control basis: The application of simple mathematical models–particularly the Heating Rate Model $(dT/dt = P_{\text{heater}}/mc)$ and the Pressure-Force Model $(F = P_{\text{pressure}} \times A)$ that provides strong technic justification for the machine design. These models enable the calculation of key component specifications, such as the required heating power (with P_{heater} approximately 30,000 Watts) and the hydraulic system strength. The relationship between operational temperature $(180-200^{\circ}C)$ and cycle time (30–45 minutes) becomes predictable, ensuring that the transferred heat (Q) is sufficient to melt mixed plastic materials (HDPE, PP, MLP) thoroughly before compaction.

Rheological Correlation and Product Quality: The pressing process successfully transforms shredded material into solid boards because the applied hydraulic pressure overcomes the high viscosity of molten plastic at elevated temperatures. The variation in plastic formulations (for example, 40% MLP for rigid boards) demonstrates that the rheology of molten plastic is a key variable. The resulting boards exhibit adjustable physical characteristics (rigid, flexible, smooth) depending on polymer ratios. The consistency of the final board dimensions ($120\,\text{cm} \times 240\,\text{cm}$) confirms the effectiveness of the cold-press and cutting systems in stabilizing the product, thereby validating the overall machine design

4.5.2. Implications for Waste Management

Solution for Hard-to-Recycle LVP: This project directly addresses the issue of low-value plastic waste, which often ends up in landfills or pollutes the environment. Plastics such as multilayer sachet packaging (MLP), which are difficult to recycle conventionally due to their layered structure, are successfully upgraded into boards. This method offers a far more beneficial utilization route compared to disposal or incineration.

Contribution to Environmental Sustainability: By converting plastic waste into useful raw materials, a significant reduction in waste volume is achieved. Furthermore, these plastic boards function as substitutes for wood and other conventional building materials, thereby reducing dependence on the exploitation of new natural resources. This represents a concrete effort toward maintaining long-term ecological balance

4.5.3. Economic and Social Impact

Creation of New Economic Value: The multipurpose boards produced have a much higher commercial value compared to the original plastic waste. These boards serve as raw materials for manufacturing various high-value products, ranging from furniture to construction components. This creates economic efficiency through reduced reliance on traditional raw materials.

Community Empowerment and Job Creation: The sheet press machine is designed for mass production at the local level, which generates substantial social impact. Implementing this technology at the community level (e.g., villages or recycling centers) creates new employment opportunities throughout the recycling value chain—from collection and sorting to product finishing. This empowers communities, strengthens local entrepreneurship, and contributes to sustainable economic growth.

4.5.4. Challenges and the Role of Policy

Implementation Challenges: Although the technical model has proven effective, operational challenges remain, such as the high electricity demand (around 30,000 Watts) and the need for heat-resistant specialty oil. Another challenge is ensuring a stable and clean supply of LVP to support mass production.

Importance of Government Policy: To ensure the sustainability of this circular economy initiative, consistent government policies are crucial. Policies should provide incentives (e.g., tax incentives or price support) for industries and communities involved in LVP recycling, along with investment in infrastructure and research. Without systematic support, circular initiatives—despite being technically feasible—will struggle to scale rapidly.

5. Conclusion

This circular economy engineering study successfully demonstrates that converting low-value plastic waste (LVP) into multipurpose boards is a technically, economically, and environmentally viable solution to the growing volume of plastic waste. A key contribution of this research is the successful validation of a robust and efficient plastic sheet press machine design, supported by technical calculations for the hydraulic and heating systems. Additionally, the simple mathematical models applied (Heat Transfer Model and Pressure–Force Model) function effectively as analytical and optimization tools for determining precise heating power requirements and compaction force, thereby ensuring consistent product quality and efficient operational cycle times (30–45 minutes at 180–200 °C). Material-wise, the conversion process successfully transforms LVP—including hard-to-recycle MLP—into dense and durable composite boards with adjustable physical properties (rigid, flexible, smooth) through variations in polymer formulation. Overall, this model embodies the principles of the Circular Economy by generating new economic value from previously worthless waste, producing end products such as furniture and construction components, and delivering positive impacts on waste reduction, resource conservation, and job creation at the community level. For future development, it is recommended to conduct comprehensive mechanical testing of the resulting boards and to develop more advanced mathematical models for real-time process control.

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