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Design and Development of a Motorized, Hydraulically-Operated Laboratory-sized Hot-Pressing Device for Particleboard Production from Agricultural Wastes

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Abstract

Introduction: The particleboard industry has increasingly turned to alternative resources, such as agricultural wastes and by-products, in response to the depletion of forest resources. Particleboard manufacturing typically involves hot-pressing, where lignocellulosic materials and binders are compressed and heated to form solid panels. However, conventional hot-pressing machines, primarily designed for mass production, are often too large for laboratory-scale experimentation and may lack the necessary adaptations to effectively process agricultural wastes. Existing machines are primarily designed for wood-based particleboard, making them less effective for agricultural waste processing. Although a manually-operated hydraulic hot-pressing device has been developed for laboratory applications, it can be labor-intensive and prone to inconsistencies in pressing conditions, such as pressure and temperature, that adversely affect product quality.

Objectives: Aiming to address the limitation of a manually operated hot-pressing device, this study is aimed to design, develop and evaluate a motorized and hydraulically-operated laboratory-sized hot-pressing device for agricultural wastes – based particleboard application.

Methods: The methods employed in the study included as follows: Identifying the design considerations as basis for the design of the device; designing the hot-press device which included the design specifications, materials selection, principle of operations of the device, design of the control panel, electrical diagrams, hydraulic system, structural frame; development, fabrication and installation of various components of the device; and, performance evaluation of the device in terms of the quality of particleboards produced using the designed hot-press device.

Results: The motorized and hydraulically-operated laboratory-sized hot-pressing device was successfully designed and developed. It has incorporated modern automation and control systems into particleboard production, enhancing the efficiency, accuracy, and repeatability of the pressing process, leading to a higher-quality products. The hydraulic system has been carefully installed, enabling the application of precise pressure essential for particleboard production. The device has been tested successfully as it can produce particleboards from various agricultural products and wastes based on the parameters considered in the study.

Conclusions: A laboratory-sized hot-pressing device which is motorized and hydraulically-operated was developed for particleboard production, making it suitable for small-scale production and experimental purposes. Performance evaluation through producing particleboards from various materials (agricultural wastes and products) and binders has been successfully demonstrated. For future study, advanced monitoring and feedback mechanisms maybe implemented to ensure consistent quality and optimize operational parameters in real-time.

Keywords: particleboards, motorized, hydraulic system, agricultural wastes, hot-pressing device, design and development

1. Introduction

Agricultural wastes, derived from the cultivation and processing of raw agricultural products—including fruits, vegetables, meat, poultry, dairy, and various crops—represent a significant yet often underutilized resource. These by-products, typically viewed as non-productive outputs, possess potential economic and environmental value that is frequently overshadowed by the costs associated with their collection, transportation, and processing [1]. Inadequate management and improper disposal of these wastes can result in severe environmental repercussions, contributing to public health nuisances and a threat to food security [2]. For instance, the burning of agricultural waste not only elevates atmospheric carbon dioxide levels—aggravating global warming—but also leads to blocked drainage systems, which can result in flooding. Furthermore, the accumulation of these wastes emits offensive odors, exacerbates air pollution, and creates breeding grounds for disease-carrying insects. Additionally, agricultural waste contributes to landfill overcrowding, remaining for extended periods until decomposition occurs.

Despite these challenges, the recycling of agricultural waste holds promising benefits both environmentally and socio-economically. When managed properly, these materials are cost-effective, abundantly available, and can mitigate the adverse environmental impacts associated with their improper disposal. Recycling agricultural solid waste can significantly reduce greenhouse gas emissions, diminish reliance on fossil fuels, and foster the development of new green markets. This not only creates jobs but also facilitates the production of bioenergy and the conversion of waste into valuable animal feed [2]. Moreover, agro-industrial waste opens avenues for innovative research in alternative fuels and energy generation [3], as well as in sustainable construction materials like bricks [4] and more.

One of the most successful approaches for managing agricultural waste is through the production of particleboards. The particleboard industry has increasingly turned to alternative resources as substitutes for traditional wood materials, driven by the depletion of forest

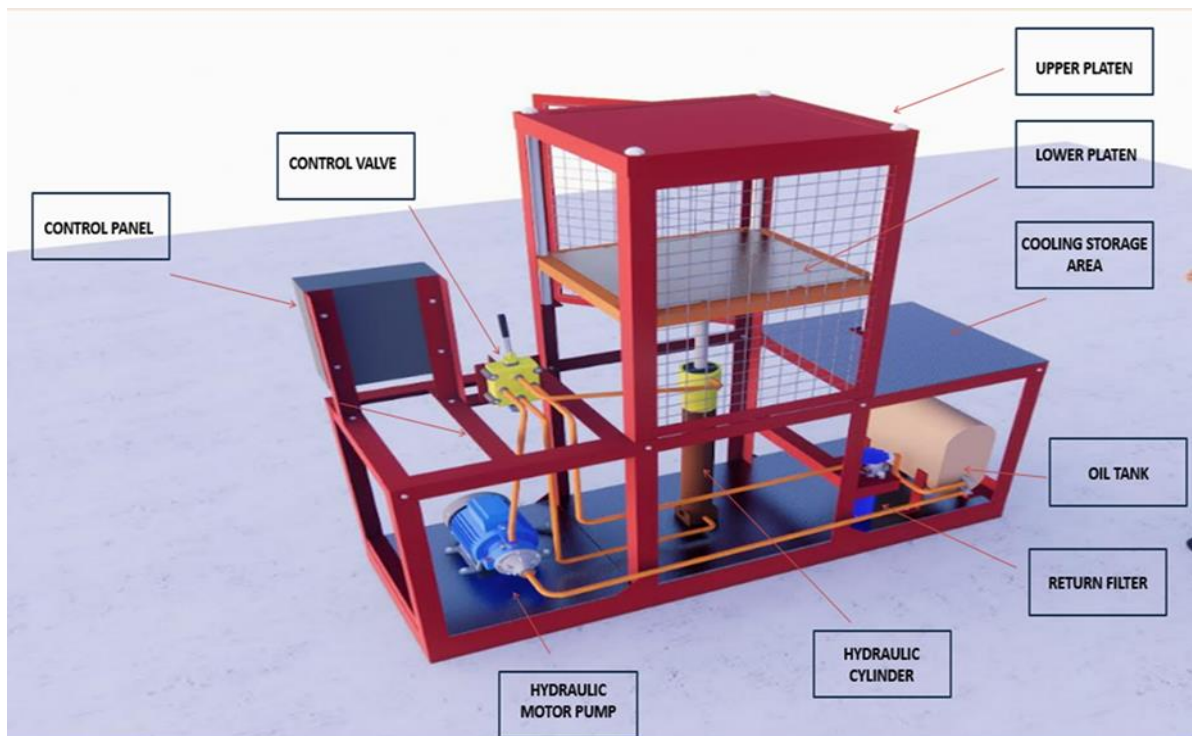
resources [5]. Extensive research has explored the use of various agricultural by-products in particleboard manufacturing, including crop wastes [6], maize cobs [7], rice husks [8], a combination of rice husk and wood sawdust [9,10,11], wheat straw [12], tree leaves [13], maize husks [14], coconut [15], banana bunch [16], palm kernel shell [17], pineapple leaves [18], among others.

The particleboard manufacturing process typically employs hot-pressing, where lignocellulosic materials and a binder are compressed and heated to form solid panels. However, conventional hot-pressing machines, primarily designed for mass production, are often too large for laboratory-scale experimentation and may lack the necessary adaptations to effectively process agricultural wastes. Although a manually-operated hydraulic hot-pressing device has been developed for laboratory applications [19], it can be labor-intensive and prone to inconsistencies in pressing conditions, such as pressure and temperature, that adversely affect product quality.

To overcome the limitations associated with manual operation, a motorized, hydraulically-operated hot-pressing device tailored for laboratory-scale production was designed and developed. This innovative device has integrated modern automation and control systems, enhancing the efficiency, accuracy, and repeatability of the particleboard manufacturing process. Preliminary testing has demonstrated its capability to produce high-quality particleboards from a variety of agricultural waste materials, establishing a valuable tool for educational institutions, small-scale manufacturers, and research laboratories with limited resources. This advancement not only facilitates research and experimentation in particleboard production but also fosters innovation and knowledge dissemination in the field.

2. Objectives

The study is aimed to address the limitations of manually operated hot-pressing device by coming-up with a motorized and hydraulically-operated hot-pressing device suitable for laboratory-scale applications. Specifically, it is aimed to: design a motorized, hydraulically-operated hot-pressing



device that integrates modern automation and control systems to enhance the efficiency, accuracy, and repeatability of the particleboard production process; develop and fabricate the hot-pressing device in accordance with detailed engineering plans and specifications, ensuring functionality and reliability; and, evaluate the performance of the newly designed hot-pressing device, assessing its effectiveness in producing high-quality particleboards from various agricultural waste materials.

3. Methods

Designing the Hot-Pressing Device

The design factors considered includes as follows: capacity, heating system, pressure system and temperature control. A moderate production capacity was considered, sufficient for laboratory-scale testing and research purposes. Meanwhile, an efficient and uniform heating system has been integrated into the device to heat the pressing plates evenly. Also, a reliable hydraulic system capable of applying and maintaining high pressures during the pressing process was ensured. And lastly, precise temperature control mechanisms has been incorporated to regulate accurately the temperature during pressing. Figure 1 shows the

schematic diagram of the device highlighting its major components. Its principles of operation are as follows:

Loading and Preparation: The process starts with loading particle board materials onto the pressing plates. Before loading, the materials were prepared by adding adhesive or other additives to enhance bonding.

Heating: The heating system of the device raises the temperature of the pressing plates to the desired level. This heating process softens the particle board materials and activates the adhesive, facilitating bonding during pressing.

Pressing: Once the materials are heated to the appropriate temperature, hydraulic pressure is applied to the pressing plate. This pressure compresses the materials together, causing them to bond and form a cohesive particle board.

Cooling and Solidification: After the pressing phase, the hydraulic pressure is released and the pressed particle board is allowed to cool. Cooling solidifies the bonding agents, resulting in a sturdy and stable particle board.

Ejection: Once the particle board has cooled sufficiently

Figure 1. Schematic diagram of device for further processing or testing.

Control and Monitoring: Throughout the operation, the device is controlled and monitored using a user interface. This interface allows operators to adjust parameters such as temperature, pressure, and pressing duration to optimize the production process and ensure consistent quality.

Safety Mechanisms: The device is equipped with safety features such as emergency stop, overpressure protection, Safety door switch and temperature monitoring to ensure safe operation and prevent accidents.

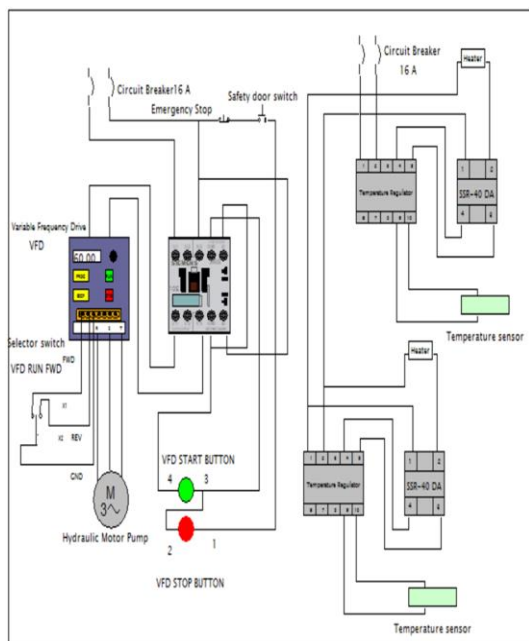
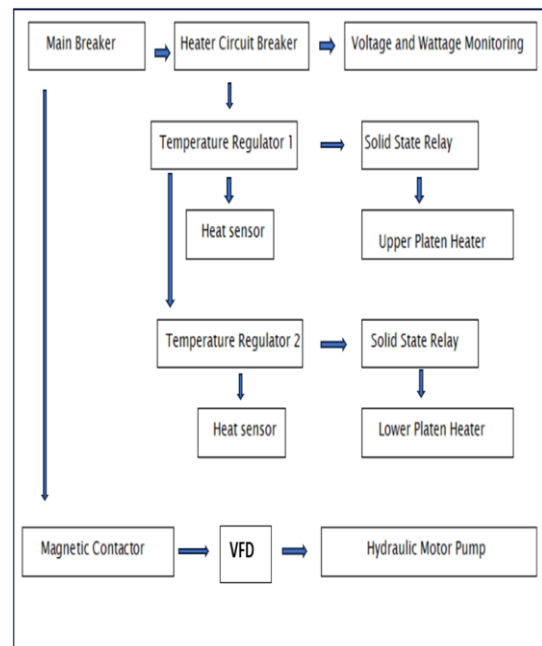


Figure 2. Block Diagram

In Figure 2, the block diagram is shown demonstrating the flow and the step-by-step procedures on the operations of the system. When both circuit breakers are turned on, the magnetic contactor then activates after pressing VFD variable frequency drive) ON button, signaling the circuit breaker to turn on the VFD. Then the selector switch is turned on to enable the VFD's run mode in forward direction and signal the hydraulic motor pump to start operating. Once the lower and higher platen temperatures reach their predetermined point values, the heating system also begins to heat up. The solid-state relay (SSR) is used to regulate the heating system. In tandem with the SSR's activation, the nichrome wire heater's indicator light begins to feed electricity and heat up. The control for the temperature regulator begins to display the values in degrees centigrade.

Figure 3 shows the electrical diagram providing a clear and concise overview of the electrical



connections and circuitry of the system. Such diagram aids to visualize the flow of electricity through a circuit and identify potential points of failure or areas for improvement. In summary, a schematic diagram model of wiring connections offers a structured representation of electrical circuits, aiding in comprehension, analysis, and design.

Figure 4 shows the frame assembly of a hot-pressing device. It provides the structural support necessary to withstand the high forces and temperatures involved in the pressing process. This assembly was constructed from heavy-duty steel.

The main frame ensures rigidity and durability, crucial for withstanding the pressure and temperatures involved in pressing. Additionally, the frame integrates hydraulic components such as cylinders, valves, and hoses to control pressure application, the proper alignment and attachment being critical for efficient operation. Safety features like interlocks, guards, and emergency stop buttons were also incorporated to protect operators during operations.

Figures 5 shows the platens assembly which constitutes a pivotal element within the hot-pressing device, essential for the successful production of particle boards. They are constructed utilizing steel materials. The platens provide a flat

and sturdy surface onto which the particle board assembly is positioned for compression and curing (Figure 5a). Embedded within these platens are heating elements (Figure 5b), responsible for generating heat necessary to facilitate adhesive curing and bond the particles together during pressing.

Assembly and Installation of Control Panel for the Hot-Pressing Device

The control panel of the device was assembled and installed. The device was utilizing a variable frequency drive (VFD) and integrating

regulators, temperature sensors, emergency stop buttons, 3-way position selector switches, light indicators, magnetic contactors, solid state relays (SSRs), and nichrome wire. The installation procedures are as follows:

Mounting and Placement of Control Panel: The control panel layout, including the placement of devices in the box enclosure, has been properly installed at its designated location.

Control Panel Wiring Connection: All designated devices were connected according to the schematic diagram.

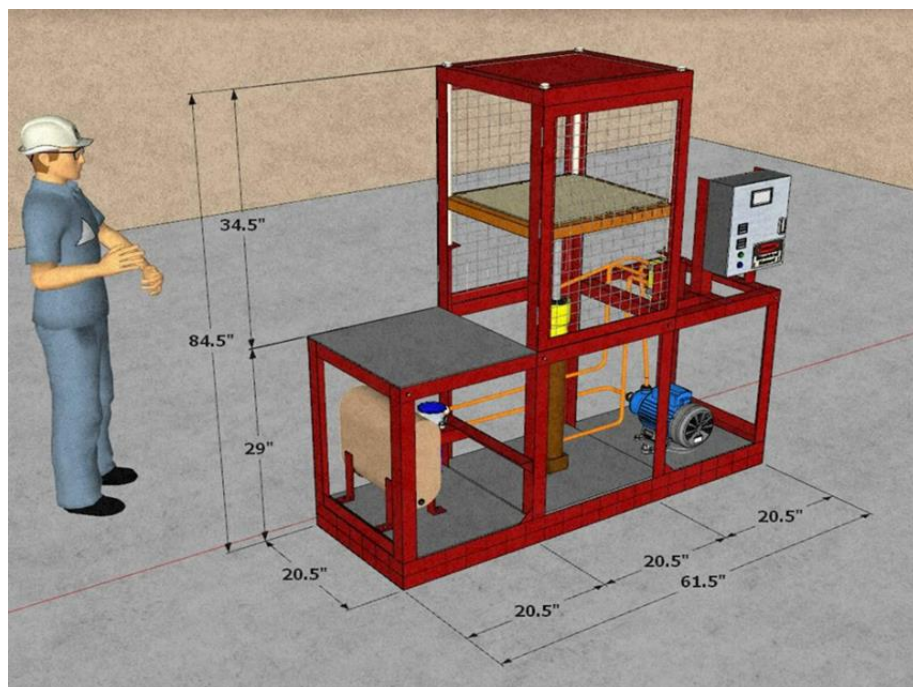
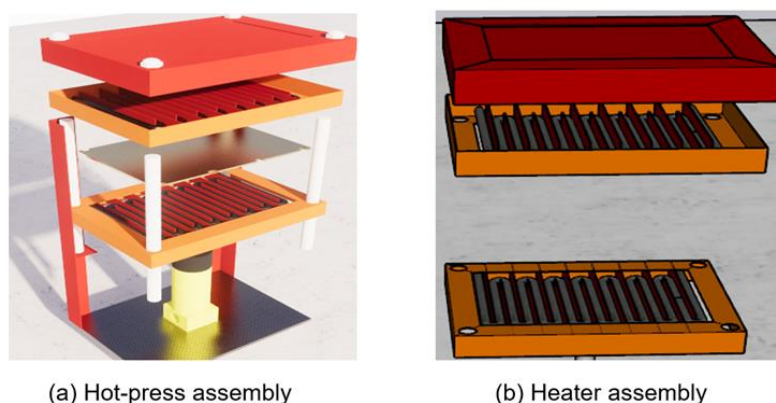


Figure 4. Frame assembly with dimensions (in inches)



(a) Hot-press assembly

(b) Heater assembly

Figure 5. The platens assembly

temperature, pressure, voltage, and kilowatt monitoring. The control panel has utilized variety of devices that include circuit breakers, temperature

Variable Frequency Drive (VFD) Configuration: The Variable Frequency Drive (VFD) was connected to an AC power source, three-phase output power,

and all motor parameters have been set in accordance with the requirements specification of the hydraulic motor pump. The following are the required parameters in VFD: F9.00- motor rated power; F9.01- motor rated voltage; F9.02- motor rated current; F9.03- motor rated speed; and, F9.04- motor rated frequency.

Connecting the Temperature Regulator: The temperature sensor was connected to a temperature controller. This controller compares the actual temperature, measured by the sensor, with the desired set value temperature required for the device. Based on the schematic electrical diagram, the controller sends a control signal to adjust the temperature accordingly.

Enclosing the Devices: All the devices, including temperature regulators, circuit breakers, and other related parts, have been enclosed to protect the system from outside influences.

Testing the System: Numerous tests and observations have been conducted to assess its performance and to ensure that the installation and assembly of the control panel is free from the risk of electrocution.

Fabrication of the Hot- Pressing Device

The fabrication process of the hot-pressing device was based on the detailed plans and specifications during the design stage that include the size, capacity, functionality as well as appropriate materials and components. The process involved cutting, bending, welding, and machining of metal parts, as well as assembling the electrical control and hydraulic systems.

Evaluation of the Performance of the Hot-Pressing the Device

After the fabrication and testing of the device, production of particleboards utilizing various agricultural products and wastes has been conducted to evaluate qualitatively its performance in producing the particle boards based on the parameters considered in the study.

Results and Discussion

Assembly and Installation of the Control Panel for the Hot-Pressing Device

Based on the design specifications and procedures outlined in the previous section, the control panel has been successfully assembled and installed. Figure 6 shows the installation of the control panel. It was properly installed at its designated location (Figure 6a). Then, all devices were electrically connected based on the electrical schematic diagram (Figure 6b). In Figure 6c, the VFD has been configured and all motor parameters were set in accordance with the requirement specifications of the hydraulic motor pump. Figure 6d shows that the temperature sensor has been connected to the temperature controller. The devices installed in the control panel have been protected from outside influences by enclosing the panel box (Figure 6e). It is then subjected to numerous testing to assess its performance (Figure 6f).

Development of the Hot-Pressing Device

Figure 7 shows the development of the device as designed in the detailed plan and specification. In Figure 7a, the structural frame is shown with the control panel, hydraulic cylinder and the electric motor mounted on it. In Figure 7b, the installed platens are shown which provide a flat and sturdy surface onto which the particleboard assembly is positioned for compression and curing. Embedded within these platens are heating elements (Nichrome wires), responsible for generating heat necessary to facilitate adhesive curing and bond the particles together during pressing. Figure 7c shows the installed hydraulic system, a critical step in the setup of a hot-press device, enabling the application of precise pressure essential for particleboard production. The major components of a hydraulic systems include the following: Double Acting Hydraulic Cylinder, Directional Control Valve (DCV), Hydraulic Pump, Electric Motor, Pressure Gauge, Hydraulic Filter and Reservoir/Tank. In Figure 8, the fabricated motorized and hydraulically-driven hot-pressing device for particleboard production is shown.

Evaluation of the Performance of the Hot-Pressing Device

Different particleboards were produced to qualitatively evaluate the performance of the designed hot-pressing device in terms of quality of the board thru visual inspection. The intention of

the evaluation is not to optimize the physical and mechanical properties of the particleboards, but to verify the performance of the designed hot-pressing device if it can produce successfully a board via visual inspection. The materials used were agricultural waste or fibers and mixed with binders or adhesives. The materials considered were sawdust particles, snake plant fiber particles, rice straw fiber particles, rice hull particles and coco husk particles. On the other hand, the binders considered were cassava starch and Styrofoam material.

In the production of Particleboard A (wood sawdust: cassava starch), sawdust particles were mixed manually with cassava starch using a wood ratio of 1kg to 0.3kg of cassava starch and 200ml of water, based on initial dimensions of 250mm x 250mm x 18mm. The mixture was then placed in the laboratory scale hot-press, which was equipped with a control valve, hydraulic cylinder, heater, and thermocouples, to produce the panels. The platen temperature was set to 150°C and the pressure was 10 kg/cm² (equivalent to 142.233 psi). After forming, the mats were manually pre-pressed to compact the materials without applying heat. Two wax paper sheets were used on both the top and bottom surfaces of the mat to prevent the boards from sticking to the hot plates during the pressing process. The mat was then transferred to a single-opening hydraulic hot press. The sawdust/starch mixture was then placed on the bottom platen, and the top platen was positioned at a 35cm height. The bottom platen was slowly lifted for 25 minutes until reaching an 12mm thickness, and then maintained at that position for an additional 5 minutes. Similar procedures have been observed to other particleboards considered.

The combination and amount of each particle and binder as well as other parameters used during hot-pressing are summarized in Table 1. Moreover, the visual inspection results of each particleboard are also included in the said table. Based on the results, all particleboards belong to a high-density category. In Figure 9, the photos of the particleboards successfully produced are shown.

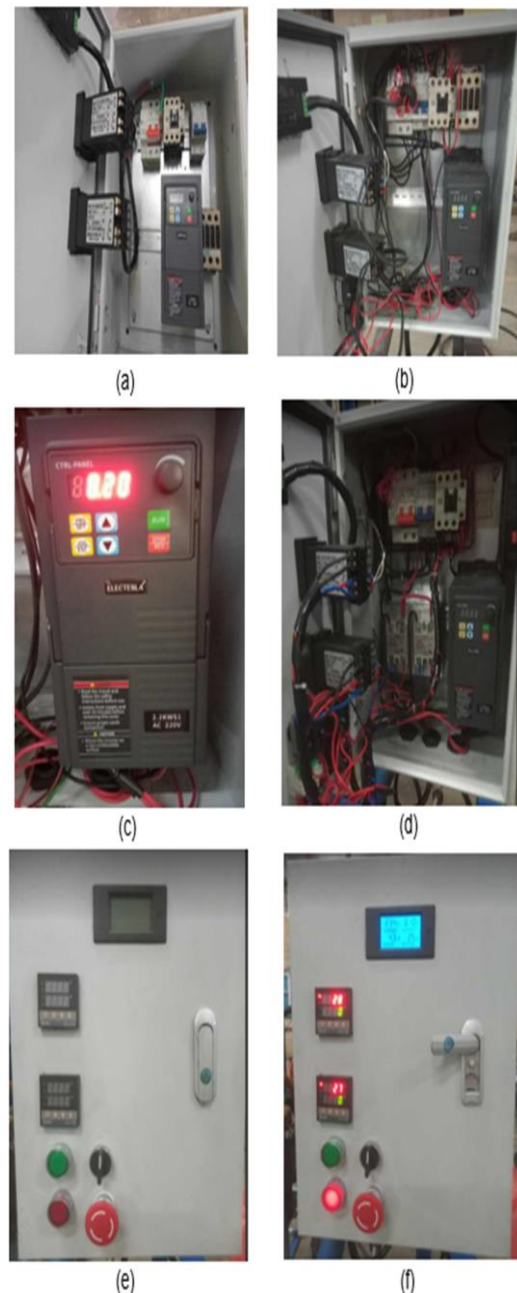


Figure 6. Installation of the control panel

4. Conclusions

In this study, a motorized and hydraulically-operated laboratory-sized hot-pressing device was successfully designed and developed for particleboard production, making it suitable for small-scale production and experimental purposes. The device has incorporated modern automation and control systems into particle board production, enhancing the efficiency, accuracy, and repeatability of the pressing process, leading to a higher-quality products. Performance evaluation

through producing particleboards from various materials (agricultural wastes and products) and binders has been successfully demonstrated. For future study, the automation and control systems of the device might be enhanced to further improve precision and efficiency in the pressing process. Moreover, advanced monitoring and feedback mechanisms maybe implemented to ensure consistent quality and optimize operational parameters in real-time.



(a) Fabrication of the structural frame



(b) Fabrication/ installation of the platens



(c) Installation of the hydraulic system components

Figure 7. Development/ installation of various components of the hot-pressing



Figure 8. The fabricated hot-pressing device



(A) Wood sawdust: Cassava starch



(B) Wood sawdust: Styrofoam



(C) Snake plant fibers: Styrofoam



(D) Rice straw: Cassava starch



(E) Rice hull: Cassava starch



(F) Coco husk: Cassava starch

Figure 9. Particleboards produced from various materials and binders

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