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# Design of Internet of Things (IoT)-Based Control System on a Hybrid Drying Machine for Sengon Wood Pallets

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**ABSTRACT**

*This study aims to design and build a sengon wood pallet drying system with an Internet of Things (IoT) based system as a monitoring and control of drying parameters such as temperature, humidity and reduction of wood mass during the drying process. Drying of sengon wood pallet samples using a combined infrared-hot air method was carried out at temperatures of 65, 75 and 85 °C and at an air velocity of 2m/s. Observation involved wood moisture content, core temperature, chamber temperatures, and air humidity which were recorded every 10 min interval during drying process. Results showed that the IoT system can function well and make the sengon wood pallet drying process monitored and controlled remotely. Wood pallet sample reached optimum conditions with moisture content of 19% at a temperature test of 85 °C. At this condition average core temperature of sengon wood pallets of 67.05 °C was recorded and a drying time of 180 min was required. The longest drying time was at a test temperature of 65 °C, with an average core temperature of 56.37 °C, and a drying time of 370 min.*

## 1. INTRODUCTION

Wood pallets are used as a base or cushion for storing and transporting goods to ensure safety and quality preservation from pre-production to post-production in the manufacturing industries (Mardatillah *et al*., 2023). The transportation of wood pallets is often carried out through forklifts or handlifts (Aryncha & Mahbubah, 2021), with high susceptibility to attack by various pests and plant diseases. To reduce the risk of attack, the government implemented phytosanitary measures for wood packaging materials in 2002 (Chan *et al*., 2023). This policy aims to reduce the possibility of pest spread and negative impacts, in line with the standard implemented by the International Plant Protection Convention (IPPC), namely the International Standard for Phytosanitary Measures No. 15 (ISPM No. 15) (IPPC, 2009). Some mandatory treatment methods include fumigation using methyl bromide gas and Heat Treatment (HT), heating to a minimum temperature of 56 °C for 30 minutes (Payette *et al*., 2015; Yusuf *et al*., 2013).

Drying of wood pallets is performed using conventional machines powered by wood, gas, or electric heating elements. The higher drying temperature is found to be correlated with a greater reduction in moisture content in wood pallets (Tzempelikos *et al*., 2009). Therefore, a mechanical wood dryer with an automatic monitoring and control system, such as Internet of Things (IoT), is required to determine drying parameters such as temperature, humidity, and water content reduction.

IoT is a technology that connects devices with on-off switches to the internet, enabling communication and formation of a network system (Syamsiana *et al*., 2024). The use of IoT for the drying process has been widely applied to conventional machines, which allows remote monitoring and controlling of the system (Damayanti *et al*., 2024).

Hariadi *et al*. (2022) have investigated the design of an intelligent drying oven machine based on IoT using a heat energy source from LPG stoves, kerosene, firewood, or coal briquettes. IoT is used to monitor temperature inside the drying oven (Hariadi *et al*., 2022). (Al-Fajri, 2022) designed a fish drying device by monitoring temperature and humidity through IoT. However, the study was limited to monitoring only, without any control over temperature and humidity in the drying room. Suprianto (2024) also used this technology in the rhizome drying process as an automation, control, and monitoring system that could be carried out remotely through a smartphone. For validation, the results of field tests obtained an average error and accuracy of percentage of 1.5% and 98.49%, respectively (Suprianto, 2024).

Despite numerous investigations, there is still limited information on the application of automatic control systems and IoT in the wood drying process. Mustikoaji *et al*. (2017) conducted a study on monitoring and controlling temperature in a wood oven for the efficiency of the drying process using Raspberry Pi as a control center (Mustikoaji *et al*., 2017). This automatic temperature controller provides conveniences such as saving energy and time, and better results due to continuous operation for 24 hours (Nurzaman *et al*., 2019). Rizki *et al*. (2019) also explored the creation of an automated wood drying system in a room using an Arduino Uno R3 microcontroller to simplify and regulate temperature. These 3 studies are still limited to automation, as drying data cannot be accessed remotely through a smartphone (Rizki *et al*., 2019). Therefore, this study aimed to design and build sengon wood pallet drying system with an IoT-based system to monitor and control temperature, humidity, and the reduction of wood mass. Testing was carried out at temperatures of 65, 75, and 85 °C with an air velocity of 2 m/s. This study limited drying time when the wood moisture content of core temperature reached 56 °C and was maintained for 30 minutes evenly across all profiles according to the ISPM standard.

## 2. MATERIALS AND METHODS

### 2.1. Material

The test material used in this study was sengon wood, obtained in the form of 3m-long logs aged approximately 5 years. The cutting process was carried out to make blocks measuring 300 mm long, 50 mm wide, and 100 mm high, in accordance with the ISO 6780:2003 standard. Sengon wood blocks were dried in the sun to remove sap and standardize moisture content to average of 35–40% dry-basis, followed by storing in an airtight container before testing.

### 2.2. Methods

This study used an experimental method to determine drying characteristics, such as changes in core temperature, moisture content, and drying rate, during the production of pallets material.

#### 2.2.1. Test Equipment

The hybrid drying machine used has a chamber dimension of 60 cm long, 60 cm wide, and 60 cm high. The heat source was from a tube-shaped infrared lamp with a power of 500 W and a tubular electric heating element with a power of 500 W. Hot air was circulated into drying chamber using a centrifugal blower with a power of 65 W. Furthermore, an exhaust fan with a size of 8 cm × 8 cm was used to maintain humidity. The decrease in wood mass was measured using a load cell with a capacity of 5 kg. This hybrid dryer uses IoT system to control temperature and humidity of the room, as shown in Figure 1a.

The combined infrared and hot air dryer was analyzed experimentally during drying of sengon wood pallets according to the ISPM 15 standard, as shown in Figure 1a. The heat source was from the heating element (2) and infrared (3), the hot air was distributed into oven chamber using a centrifugal blower (1). Sengon wood pallets (5) were placed above the load cell (4) to determine the decrease in moisture content and the vapor from drying was released through the exhaust (6). This process used a closed system where the air from heating wood was circulated through the circulation pipe (8), sucked by the centrifugal blower. To determine the uniformity of temperature, measurements were taken at 3 points in wood core. The IoT system functions to control the temperature and monitor the drying process, the sengon wood drying process is carried out at a temperature of 65, 75 and 85 °C with a

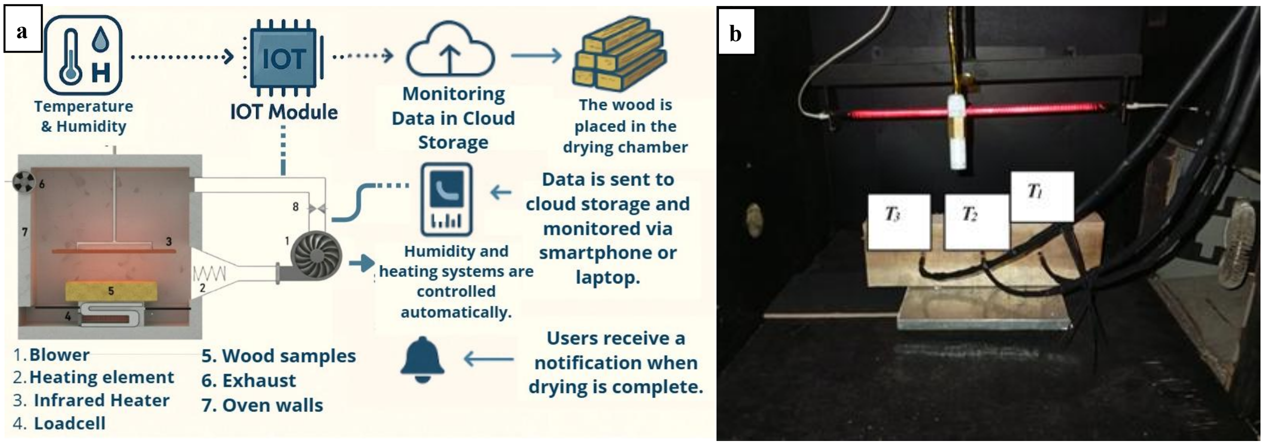


Figure 1. (a) Schematic of IoT system on a hybrid drying machine for drying sengon wood pallets, and (b) Placement of the wood sample above the load cell and 3 temperature sensors to measure the core temperature of the wood.

maximum humidity of 20%, when the room temperature has reached the target, the IoT component works to turn off the heater and turn it back on if the room temperature drops according to the upper and lower limits that we enter, namely ±3 °C. The monitoring data displayed by the IoT system is in the form of 3 data points on the core temperature of the wood and the decrease in the mass of sengon wood as shown in Figure 1b. This was followed by data collection on core and room temperature, as well as air humidity at every 10 min interval during drying process until wood sample reached moisture content of 19%. Subsequently, dried samples were oven-dried at a temperature of ±103 °C for 24 h to obtain the equilibrium moisture content.

### 2.2.2. System Design

System design is an important part of the implementation of IoT on a hybrid drying machine. In this study, IoT system was used to monitor and control temperature, humidity, and wood mass reduction, allowing remote supervision of drying process through an internet network using a smartphone. The platform selected was ThingSpeak, an open-source and paid IoT platform created by MathWorks, the developer of MATLAB. This platform provides tools for showing data instantly through graphics, as well as built-in analytical capabilities for analyzing and processing data, which can be integrated with a microcontroller. For this study, ESP32 microcontroller was used to process program data and show the results, allowing continuous control and monitoring of wood drying parameters in the form of values and graphs.

Three DS18B20 temperature sensors are used to determine the temperature distribution in sengon wood, installed at a depth of 2.5 cm in the wood. Specifically, SHT31 was used to monitor room temperature and humidity as well as regulate infrared and heater elements to maintain the desired target. The Load Cell and HX711 Module functioned as tools for reading the decrease in wood mass. Drying data in the form of room temperature, humidity, wood core temperature, and wood mass reduction were monitored and stored in real time in ThingSpeak cloud with an automatic protection system shown in Figure 2.

## 3. RESULTS AND DISCUSSION

### 3.1. Drying Data Display

Figure 3 shows display of ThingSpeak platform, which consists of two types of outputs, namely value data and graphs. The data display includes 3 wood core temperature (T1, T2, and T3), air humidity, wood mass reduction, and room temperature regulating the infrared and heater element in an on or off condition. Subsequently, testing was carried out on ThingSpeak cloud for remote monitoring to ensure that drying parameters were stored in real time. Android platform was used to retrieve stored data through an internet connection, ensuring display of the same information as the web server.

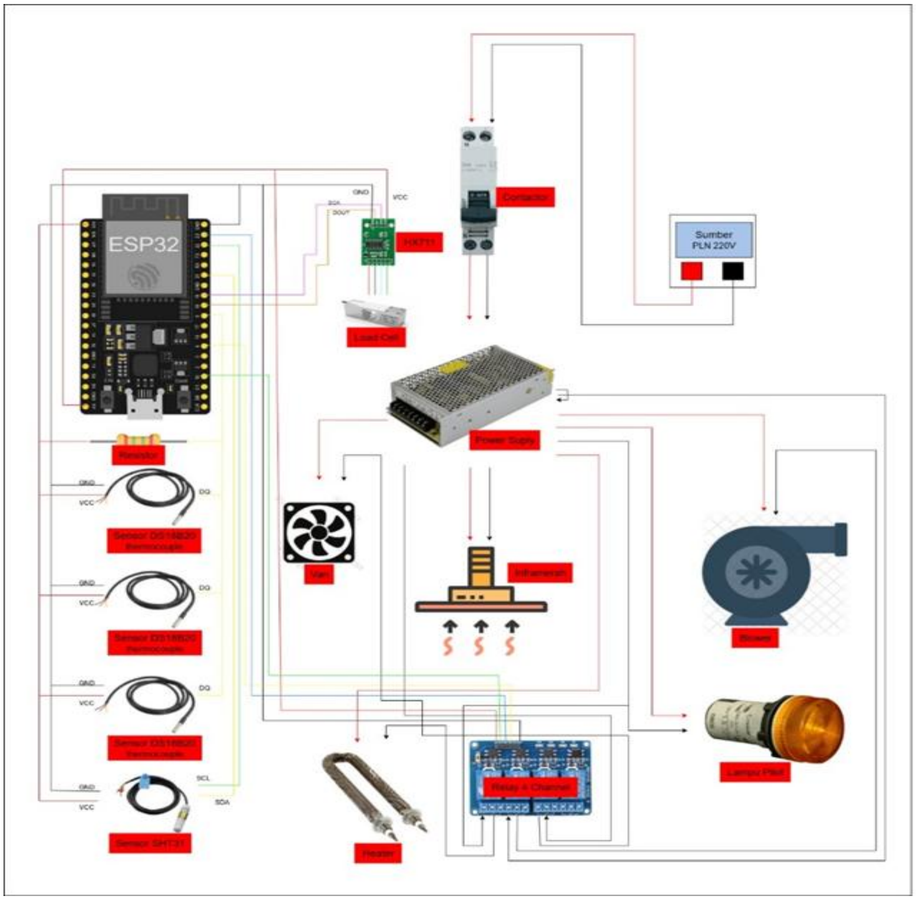


Figure 2. Design of the IoT system on a hybrid drying machine

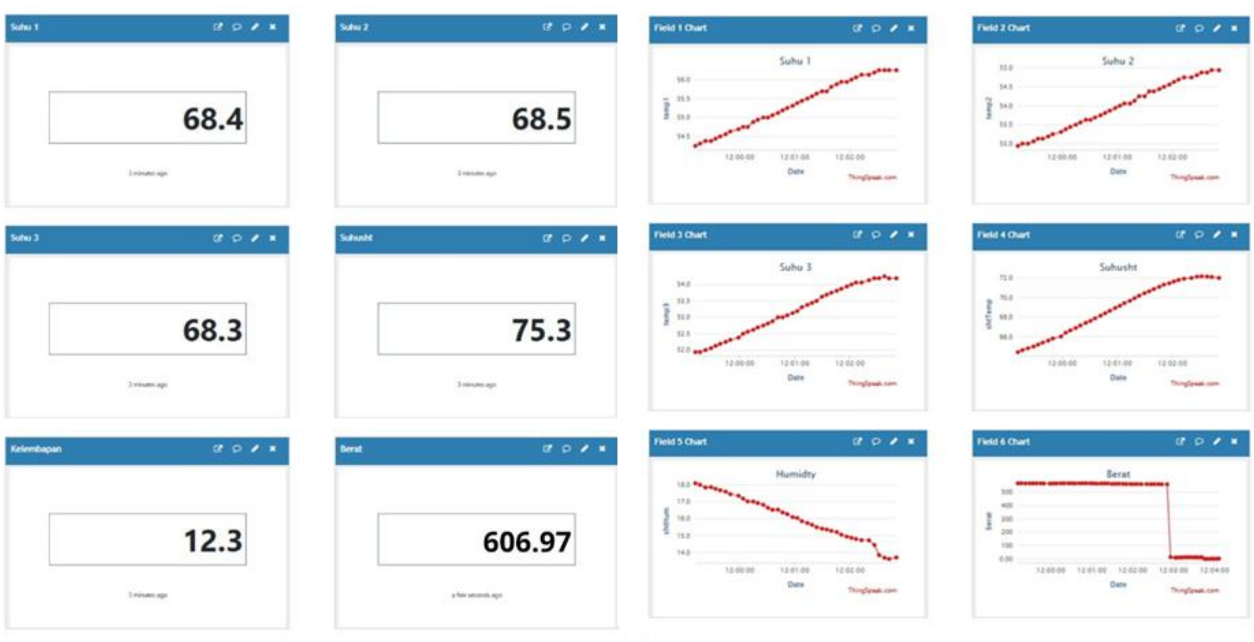


Figure 3. Drying data display on ThingSpeak

### 3.2. Drying Performance

The results of drying sengon wood using the hybrid infrared-hot air heating method at temperatures of 65, 75 and 85 °C at an air velocity of 2 m/s are shown in Table 1.

Table 1. Data on drying results of sengon wood pallets

| Drying methods | Air velocity (m/s) | Temperature (°C) | Wood Core Temperature (°C) | Moisture content (bk %) | | Drying rate (gr/minute) | Drying time (Minutes) |
|---|---|---|---|---|---|---|---|
| | | | | mo | mt | | |
| Infrared-Hot air | 2 | 65 | 56.37 | 36.18 | 19.95 | 0.18 | 370 |
| | | 75 | 59.32 | 39.77 | 19.76 | 0.39 | 210 |
| | | 85 | 67.05 | 36.58 | 19.63 | 0.36 | 180 |

As presented in Figure 4a, the highest core temperature profile of sengon wood pallets using the combined infrared-hot air method was at 85 °C, reaching 67.05 °C. These results showed that drying process could occur uniformly. The combination of infrared light and hot air caused a faster increase in temperature in drying chamber, enhancing the release of vapor in wood (Chan *et al*., 2024). Infrared radiation has unique radiation properties as heat energy is directly concentrated on the material. This allows heating homogeneity with a high heat transfer coefficient, a short time, and low energy consumption. In comparison, hot air provides a deeper heat penetration effect on wood (Filková & Mujumdar, 2020; Sabau *et al*., 2020).

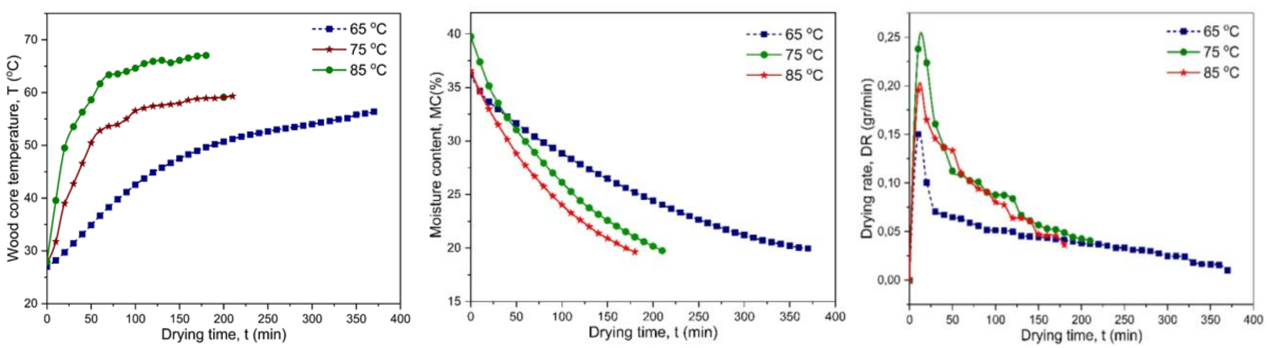


Figure 4. (a) Core temperature profile of sengon wood pallets during drying, (b) The decrease in moisture content of sengon wood pallets, and (c) Drying rate of sengon wood pallets

The increase in air temperature in the drying chamber caused evaporation, thereby decreasing moisture content. Initially, vaporization process occurs on the surface of the sengon wood due to the difference in vapor pressure between wood and the environment, as shown in Figures 5b and 5c. When the wood surface begins to dry, an imbalance in moisture content occurs between the outside and inside. Therefore, moisture moves from wood interior to the surface, where free water evaporates, followed by bound molecules (Chan *et al*., 2025). Reduction of moisture content at a temperature of 85 °C takes place faster than drying at 75 °C and 65 °C. However, at 75 °C, the drying rate is greater compared to 85 °C and 65 °C. This is due to the initial moisture content of sengon wood at 75 °C treatment being higher, namely 39.77% on a dry basis.

## 4. CONCLUSION

In conclusion, the drying process of sengon wood pallets was carried out using IoT technology. System control and monitoring were carried out through the Android platform on a smartphone. The results show that IoT can assist the wood drying process by regulating air temperature and humidity, while ensuring reliable data storage for analysis purposes. Sengon wood pallets with an average initial moisture content of 37.5% were dried using a combined infrared-hot air method to 19% with variations in test temperature of 65, 75, and 85 °C, as well as air velocity of 2 m/s. The optimum drying conditions at a temperature of 85 °C produced an average wood core temperature of 67.05

°C with a drying time of 180 minutes. The longest drying time was at test temperature of 65 °C, with an average wood core temperature of 56.37 °C, and a drying time of 370 minutes.

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## AUTHOR CONTRIBUTION STATEMENT

| Author | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YC | ✓ | ✓ | | | ✓ | | ✓ | | ✓ | ✓ | | ✓ | | |
| SS | | | ✓ | ✓ | | | ✓ | ✓ | | | ✓ | ✓ | ✓ | |
| WNS | | | ✓ | | | | | ✓ | | | ✓ | | | ✓ |
| ZLA | | | | | | | | ✓ | | | | | | ✓ |

| | | | |
|---|---|---|---|
| C: Conceptualization | Fo: Formal Analysis | O: Writing - Original Draft | Fu: Funding Acquisition |
| M: Methodology | I: Investigation | E: Writing - Review & Editing | P: Project Administration |
| So: Software | D: Data Curation | Vi: Visualization | |
| Va: Validation | R: Resources | Su: Supervision | |

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