# Raspberry Pi-Based Chiller Control System Using the Fuzzy Logic Method for Granular Products

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***Abstract*- The cooling process of granular products requires stable temperature control to maintain material quality. Conventional chiller systems with manual control tend to produce significant temperature fluctuations and operate less efficiently. This study proposes a Raspberry Pi-based chiller control system using the fuzzy logic method to improve temperature stability and enable real-time monitoring through the Internet of Things (IoT). The system utilizes the DS18B20 sensor for temperature measurement and the DHT22 sensor for humidity measurement, with a Peltier TEC1-12706 module serving as the cooling actuator and a blower fan functioning as the humidity controller. The fuzzy logic method is applied to determine the cooling performance level based on the measured temperature conditions. The test results indicate that the system is capable of regulating temperature adaptively, with a measurement error of ±0.89% for the DS18B20 temperature sensor and ±3.33% for the DHT22 humidity sensor. The actuators operate according to the detected conditions, where the Peltier TEC1-12706 functions at three levels (maximum, medium, and off), while the blower fan is activated when the humidity exceeds 70%. The implementation of this system demonstrates improved temperature stability and control effectiveness compared to conventional methods, making it suitable for application in small- to medium-scale granular product cooling systems.**

***Keywords—Internet of Things (IoT), fuzzy logic, chiller, granule, Peltier***

## I. INTRODUCTION

A chiller is a device that functions to reduce the temperature of a fluid through a heat transfer process by utilizing a refrigeration cycle consisting of a compressor, condenser, evaporator, and expansion device [1]. In addition to these conventional systems, there are also chillers that utilize waste heat as an energy source without using a mechanical compressor. This system operates based on the absorption principle, in which low-pressure refrigerant vapor is absorbed and then transferred to a high-pressure generator to undergo a desorption process through heating. This demonstrates that chiller technology has various operating methods that can be adapted to different energy requirements and application needs.

In industrial applications, chiller systems play an important role not only in air conditioning but also in maintaining temperature stability for equipment and products that are sensitive to temperature changes [2]. Proper temperature control is essential to preserve product quality and characteristics, particularly in production processes involving specific materials. In addition, the use of chillers has been proven to improve overall system performance. One study showed that reducing the inlet ambient temperature through the use of a chiller can increase generator output, thereby contributing to better operational efficiency [3].

Along with technological advancements, chiller systems continue to evolve, one of which is through the use of thermoelectric modules (Peltier) that offer a simpler, more flexible, and energy-efficient cooling solution for small-scale applications [4]. This technology enables the integration of cooling systems with automatic temperature and humidity control, making it highly suitable for applications that require precise environmental condition control. Furthermore, this approach opens opportunities for the development of more compact and easily implementable chiller systems.

On the other hand, the development of Industry 4.0 demands systems that are capable of operating automatically, adaptively, and in integration with digital technology. Cooling systems that still rely on manual adjustment are considered less efficient and less responsive to real-time condition changes. The implementation of Internet of Things (IoT) technology enables monitoring and control systems to operate more efficiently and in real time, Periodic monitoring does not represent the actual condition of a system at all times; therefore, an automatic real-time monitoring system is required thereby improving overall system performance [5] [6]. Therefore, a control method is required to handle non-linear system characteristics and uncertainties. One widely used method is fuzzy logic, which is capable of mimicking human reasoning in decision-making without requiring complex mathematical models. A Fuzzy Logic Controller (FLC) enables the system to provide more flexible and adaptive responses to changing conditions, making it highly suitable for implementation in dynamic cooling systems [7].

The use of chiller systems in processes involving granular products plays an important role in maintaining the physical characteristics of the material. The implementation of a chiller-based cooling reservoir in composite material processing before being cut into pellets (granules) has been proven to significantly reduce the material temperature. This controlled cooling process produces pellets with better quality and more uniform sizes. In addition, optimal temperature control also affects the stability of the material's mechanical properties and helps prevent deformation caused by high temperatures during the process [8].

Based on the description above, this study proposes the development of a Raspberry Pi-based chiller control system using the fuzzy logic method that not only focuses on temperature control but also integrates humidity control simultaneously within a single system. Unlike previous studies that generally emphasized only temperature control or employed conventional control methods, the proposed

system is capable of providing more adaptive responses to environmental condition changes through a fuzzy logic approach. In addition, the integration of Internet of Things (IoT) technology enables real-time monitoring, thereby improving operational efficiency and simplifying system supervision. With this combination, the proposed study is expected to produce a chiller system that is more flexible, economical, and suitable for small- to medium-scale granular product cooling applications.

## II. MATERIALS AND METHODS

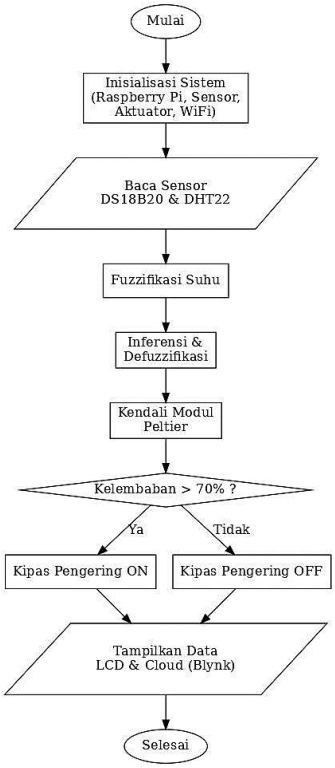



Fig 1. *Flowchart* Sistem

Overall, this software design ensures that temperature and humidity data obtained from the sensors can be processed effectively and translated into appropriate control actions for the output devices. The integration of the system with Blynk makes the system more flexible, efficient, and supportive of the implementation of the Internet of Things (IoT) concept in chiller control for granular products.

### *A.* Hardware Design

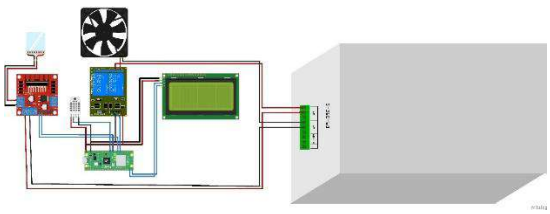


Fig 2. *Schematic Diagram*

The circuit schematic in Figure 2 illustrates the integration of Raspberry Pi 4 Model B as the controller, Raspberry Pi is widely utilized as a mini-computer capable of processing sensor data and controlling system operations in real time [9]. DS18B20 and DHT22 as input devices, as well as the Peltier TEC1-12706 module and two DC fans as actuators in the chiller system for cooling and reducing the humidity of granular products. The DS18B20 sensor is used to measure the temperature of the granules, while the DHT22 monitors the temperature and humidity conditions inside the chiller. The sensor data are processed using the fuzzy logic method to regulate the operation of the Peltier module and threshold-based logic to control the drying fan.

The system uses two fans, namely a Peltier cooling fan to dissipate heat from the hot side of the module, and a blower fan to improve air circulation and accelerate the reduction of granule humidity. The blower fan is activated when the humidity exceeds a predetermined threshold. All actuators are controlled through a driver by the Raspberry Pi 4 Model B, and the system status information is displayed on an LCD to facilitate monitoring. The fans are controlled using the L298N Motor Driver Module driver module, which operates with a 5 V logic supply and approximately 12 V motor power supply, and is capable of handling currents up to ±2 A per channel. This module is used to regulate the direction and speed of DC motors through logic and PWM signals from the microcontroller [10].

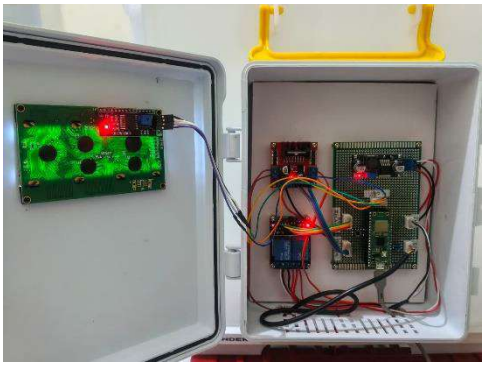


Fig. 3. Electronic Circuit Design

Figure 3 shows the hardware configuration of the Raspberry Pi-based chiller control system integrated into a single enclosure, consisting of the controller, driver modules, and sensor and actuator connections. The system is designed in a compact form to simplify installation and operation. With this configuration, the system is capable of maintaining temperature stability while effectively reducing humidity, thereby preserving the physical quality of the granules during the cooling process. Raspberry Pi 4 Model B is an IoT-based open-source device that functions as a mini computer running the Linux operating system. Despite its compact size, this device is equipped with complete features such as RAM, a USB-C port for power supply, and a microSD slot for storage media, allowing it to function similarly to a conventional computer [11]. In addition to serving as a mini computer, Raspberry Pi is widely used in IoT applications, such as Bluetooth Low Energy (BLE)-based monitoring systems [12].

*B.* Prototype Layout Design

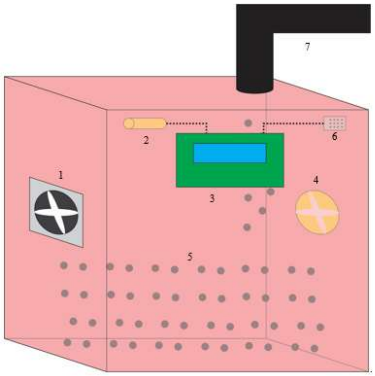



Fig. 4. Prototype Schematic Design

The chiller system prototype shown in Figure 4 consists of several main components, namely: (1) a Peltier TEC1-12706 module as the cooling element used to reduce the temperature inside the chiller chamber. The Peltier module operates based on the thermoelectric effect, which produces a temperature difference when supplied with electric current. One side absorbs heat (cold side), while the other side releases heat [13]; (2) a DS18B20 sensor used to measure the temperature of the granules. The DS18B20 communicates with the microcontroller through a digital sensor interface using the 1-Wire protocol [14]. This sensor has three wires, namely red (+), yellow (data), and black (−). In the circuit, a 4.7 kΩ pull-up resistor is connected between the data line and VCC [15]; (3) a component box containing the Raspberry Pi Pico W, driver module, and LCD, which function as the system processing and display center. Furthermore, (4) a DC fan functions to circulate air and assist the drying process under humid conditions; (5) granules as the cooling object; (6) a DHT22 sensor to detect humidity; and (7) a pipe serving as the inlet path for granules into the chiller chamber.

The prototype dimensions were designed to be approximately 40 × 40 × 45 cm to ensure uniform granule distribution while providing sufficient space for air circulation and component installation. The structure uses lightweight materials such as acrylic with a cubic shape to simplify assembly and observation. The inlet pipe, with a diameter of approximately 5–7 cm, allows granules to flow smoothly into the system without disturbing the temperature stability inside the chiller..

The components are strategically positioned, where the DS18B20 sensor is placed near the granule zone to obtain more accurate temperature readings, while the LCD is installed on the front side to facilitate monitoring. A 20×4 LCD generally uses the HD44780 controller and can operate in either 4-bit or 8-bit mode, with the 4-bit mode being more efficient in terms of pin usage. This module is equipped with control pins such as RS, RW, and E to manage data transmission and displays characters in a 5×8 pixel matrix format [16]. The DC fan is positioned on the side of the prototype to improve air circulation and accelerate humidity reduction, while the ventilation serves as the outlet path for humid air. With this configuration, the system is capable of cooling and drying the granules evenly, thereby maintaining the physical quality of the granules throughout the process.



Fig 5. Prototype Device

Fig. 5 shows a box-shaped chiller prototype equipped with fans as the air circulation system. This design enables the cooling and humidity reduction processes to occur evenly inside the chiller chamber..

*C. Fuzzy Logic Implementation*

The implementation of fuzzy logic in this chiller control system aims to regulate the cooling and drying processes of granular products adaptively based on temperature and humidity conditions. The fuzzy logic method was selected because it is capable of handling non-linear and uncertain condition changes, while also providing smoother control responses compared to conventional ON–OFF control systems.

a) Determination of Fuzzy Variables

TABLE 1. VARIABEL *FUZZY*

| No | Jenis Variabel | Nama Variabel | Rentang Nilai | Kategori Linguistik |
|---|---|---|---|---|
| 1 | *Input* | DS18B20 | 30–70 °C | Normal – Sedang – Tinggi |
| 2 | *Output* | *Peltier* | 0–255 (PWM) | Mati – Sedang – Maksmum |
| 3 | *Output* | Kipas DC | 0–255 (PWM) | Mati – Menyala |

In Table 1, the granule temperature variable serves as the main input in the fuzzy system, obtained from the DS18B20 sensor with a range of 30°C to 70°C, and is used to determine thermal conditions as the basis for decision-making. The Peltier power variable, as the output, is used to regulate the cooling level in the form of PWM values (0–255), where higher values indicate greater cooling intensity. In addition, the fan speed variable is also represented in PWM values (0–255) to control air circulation and assist the drying process under high humidity conditions.

b) Determination of Membership Functions

The system output is the Peltier cooling fan (PWM) with a value range of 0–255. The membership functions for each output are described as follows:

TABLE 2. MEMBERSHIP FUNCTIONS

| Suhu (°C) | μ Normal | μ Sedang | μ Tinggi |
|---|---|---|---|
| 30 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 |
| 35 | 1 | 0 | 0 |
| 36 | 0 | 0.13 | 0 |
| 40 | 0 | 0.67 | 0 |
| 45 | 0 | 0.67 | 0 |
| 50 | 0 | 0 | 0.33 |
| 55 | 0 | 0 | 0.67 |
| 60 | 0 | 0 | 1 |
| 65 | 0 | 0 | 1 |
| 70 | 0 | 0 | 1 |

Table 2 presents the membership degree values of the temperature variable for three fuzzy sets, namely normal,

medium, and high. The membership degree value (μ) ranges from 0 to 1, where a value of 0 indicates that the variable does not belong to the set, while a value of 1 indicates full membership.

Based on the table, it can be observed that each temperature value may have more than one membership degree in different fuzzy sets. This is a characteristic of fuzzy systems that enables smooth transitions between conditions, unlike binary logic systems.

For example, at a temperature of 40°C, the membership degree is 0.67 in the medium set, indicating that the temperature is predominantly categorized as medium. Meanwhile, at 50°C, a transition begins from the medium category toward the high category.

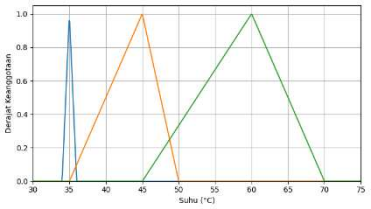



Fig. 6. Membership Function Graph

Figure 6 illustrates the temperature membership function graph in the fuzzy system, which consists of three sets: normal, medium, and high. This graph is used as the basis for the fuzzification process to determine the level of cooling control. The membership function used in this study is the triangular membership function because it has a simple structure and is easy to implement in control systems.

c) Fuzzy Rules

TABLE 3. *FUZZY RULES*

| No | Sensor | Suhu (°C) | Kelembaban (%) | IF (Kondisi) | THEN (*Peltier*) |
|---|---|---|---|---|---|
| 1 | DS18B20 & DHT22 | Panas | Minimal | IF Suhu panas AND Kelembaban Minimal | *Peltier* Tinggi |
| 2 | DS18B20 & DHT22 | Panas | Maksimal | IF Suhu panas AND Kelembaban Maksimal | *Peltier* Tinggi |
| 3 | DS18B20 & DHT22 | Sedang | Minimal | IF Suhu sedang AND Kelembaban Minimal | *Peltier* Sedang |
| 4 | DS18B20 & DHT22 | Sedang | Maksimal | IF Suhu sedang AND Kelembaban Maksimal | *Peltier* Sedang |
| 5 | DS18B20 & DHT22 | Normal | Minimal | IF Suhu ideal AND Kelembaban Minimal | *Peltier* Rendah / Mati |
| 6 | DS18B20 & DHT22 | Normal | Maksimal | IF Suhu ideal AND Kelembaban Maksimal | *Peltier* Rendah / Mati |

TABLE 4. DRYING FAN CONTROL RULES

| No | Sensor | Kelembaban (%) | Kondisi | Status Kipas Pengering |
|---|---|---|---|---|
| 1 | DHT22 | > 70 % | Lembab | ON |
| 2 | DHT22 | ≤ 70 % | Tidak lembab | OFF |

Table 2 presents the fuzzy rules used to classify the control actions to be performed. When the granule temperature is high (60–70°C), the system classifies the granules as hot and activates the Peltier TEC1-12706 at the maximum level to accelerate the temperature reduction process. Under this condition, the primary focus is on cooling, while the drying fan is controlled separately based on the humidity threshold.

When the temperature is within the medium range (40–50°C), the Peltier module operates at a medium level to gradually reduce the temperature and maintain stable conditions inside the chiller. This approach is intended to prevent excessively rapid temperature drops that could affect the quality of the granules.

When the temperature reaches the normal range (34–35°C), the Peltier TEC1-12706 module is turned off. However, if the humidity remains above 70%, the drying fan will be fully activated to reduce the moisture content without affecting the temperature. Conversely, if the humidity is already ≤70%, all actuators will be turned off, indicating that the cooling and drying processes have been completed in accordance with Table 3, which presents the drying fan control rules.

d) Formation of Fuzzy Sets

The granular product temperature variable (T) is divided into three fuzzy sets, namely Normal, Medium Heat, and High Heat.

Normal Fuzzy Set (34–36 °C)

$$u_{normal}(T) = \begin{cases} 0, & T \le 34 \\ \dfrac{T-34}{35-34}, & 34 < T \le 35 \\ \dfrac{36-T}{36-35}, & 35 < T < 36 \\ 0, & T \ge 36 \end{cases} \quad (1)$$

Medium Heat Fuzzy Set (35–50 °C)

$$u_{sedang}(T) = \begin{cases} 0, & T \le 35 \\ \dfrac{T-35}{45-35}, & 35 < T \le 45 \\ \dfrac{50-T}{50-45}, & 45 < T < 50 \\ 0, & T \ge 50 \end{cases} \quad (2)$$

High Heat Fuzzy Set (45–70 °C)

$$u_{tinggi}(T) = \begin{cases} 0, & T \le 45 \\ \dfrac{T-45}{65-54}, & 45 < T \le 60 \\ \dfrac{70-T}{70-65}, & 65 < T < 70 \\ 0, & T \ge 70 \end{cases} \quad (3)$$

The Peltier power output (P) is represented in the form of PWM values with a range of 0–255.

Peltier OFF Fuzzy Set (0–80 PWM)

$$u_{mati}(P) = \begin{cases} 1, & P \le 0 \\ \dfrac{80-P}{80}, & 0 < T \le 80 \\ 0, & P \ge 80 \end{cases} \quad (4)$$

Medium Peltier Fuzzy Set (80–180 PWM)

$$u_{sedang}(P) = \begin{cases} 0, & P \leq 80 \\ \dfrac{P - 80}{128 - 80}, & 80 < P \leq 128 \\ \dfrac{180 - P}{180 - 128}, & 128 < P < 180 \\ 0, & P \geq 180 \end{cases} \quad (5)$$

Maximum Peltier Fuzzy Set (180–255 PWM)

$$u_{maks}(P) = \begin{cases} 0, & P \leq 180 \\ \dfrac{P - 180}{225 - 180}, & 180 < T \leq 225 \\ 1, & P \geq 225 \end{cases} \quad (6)$$

e) Inference and Defuzzification

The inference process in this system uses the Mamdani method, where the membership degree of each rule is determined using the minimum (MIN) operator, while the results of all rules are combined using the maximum (MAX) operator. After the inference stage is completed, a defuzzification process is carried out to convert the fuzzy output into a crisp value that can be used by the system to control the actuators.

The defuzzification method used is the Center of Area (COA) or centroid method, because this method is capable of producing an output value that represents a weighted average based on the area of the membership functions. The equation used is as follows:

$$Z = \frac{\sum_{i=1}^{n} u_i \; x \; z_i}{\sum_{i=1}^{n} u_i} \quad (7)$$

where $\mu_i$ represents the membership degree obtained from the inference process, and $z_i$ is the output value of each rule. The defuzzification result is then used as a control signal in the form of PWM (Pulse Width Modulation) sent to the actuators. The higher the generated PWM value, the greater the power delivered, resulting in increased fan rotation speed or higher actuator output intensity.

## III. RESULTS AND DISCUSSION



Fig. 7. Prototype Testing

To ensure the performance of the device, several testing stages were conducted, including temperature testing, humidity testing, and overall system testing. The following section describes the procedures and the design of the testing tables provided for recording the results.

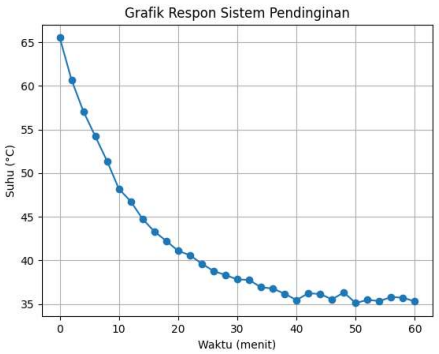



Fig. 8. Testing Graph

Figure 8 illustrates the cooling system response over a 60-minute testing period, where the initially high temperature gradually decreases until it approaches the target temperature. At the beginning of the process, the temperature drops more rapidly because the system activates the Peltier TEC1-12706 module at its maximum level. As time progresses and the temperature enters the medium category, the rate of temperature reduction becomes more stable because the system adjusts the cooling performance level based on the fuzzy logic method.

In the final phase, when the temperature approaches the normal condition, the temperature reduction becomes slower and tends to stabilize. Slight fluctuations can be observed in the curve, reflecting the dynamic response of the system to environmental changes and the adaptive characteristics of fuzzy logic control. Nevertheless, the system is still capable of maintaining temperature stability without significant overshoot, indicating effective and smooth control performance.

### *A. Temperature and Humidity Sensor Testing*

The testing was conducted to evaluate the performance of the DS18B20 sensor in measuring temperature and the DHT22 sensor in measuring humidity within the chiller system. The tests were performed by comparing the sensor readings with reference measuring instruments under several conditions.

TABLE 5. TEMPERATURE SENSOR TESTING

| No | Kondisi | Suhu Referensi (°C) | Suhu Sensor (°C) | *Error* (%) |
|---|---|---|---|---|
| 1 | Panas | 60 | 59.5 | 0.83 % |
| 2 | Sedang | 45 | 44.6 | 0.89 % |
| 3 | Normal | 35 | 34.8 | 0.57 % |

Based on the test results, the DS18B20 sensor was able to measure temperature with good accuracy, showing a relatively small error value of 0.89%. This indicates that the sensor is suitable for use as the main input in the fuzzy system.

TABLE 6. HUMIDITY SENSOR TESTING

| No | Kondisi | Kelembaban Referensi (%) | DHT22 (%) | *Error* (%) |
|---|---|---|---|---|
| 1 | Kering | 60 | 62 | 3.33 % |
| 2 | Sedang | 70 | 72 | 2.86 % |
| 3 | Lembab | 80 | 79 | 1.25 % |

The test results show that the DHT22 sensor has a fairly good level of accuracy, with a maximum error of 3.33%. This sensor is capable of detecting humidity

changes effectively, making it suitable for use as a parameter for controlling the drying fan.

### *B. Actuator Testing*

The testing was conducted to evaluate the performance of the blower fan in assisting the air circulation process and the operating characteristics of the Peltier TEC1-12706 module during the cooling process. The observed parameters included voltage, current, and rotational speed (RPM).

TABLE 7. DRYING FAN TESTING

| No | Tegangan (V) | Arus (A) | Kecepatan (RPM) | Status |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | OFF |
| 2 | 7,5 | 0.53 | 2542 | ON |
| 3 | 10 | 0.53 | 5027 | ON |

TABLE 8. PELTIER MODULE TESTING

| No | Tegangan (V) | Arus (A) | Status |
|---|---|---|---|
| 1 | 0 | 0 | OFF |
| 2 | 7,5 | 3.55 | ON |
| 3 | 10,2 | 3.55 | ON |



Fig. 9. Voltage and Current Testing

The test results show that the current consumed by the Peltier TEC1-12706 module increases along with the increase in voltage. Under maximum operating conditions, the module operates at a voltage of 10.2 V with a current of 3.55 A. This indicates that the Peltier module requires relatively high power to produce the cooling effect, and therefore must be supported by an effective heat dissipation system to maintain optimal performance.

### *C. Internet of Things (IoT) Testing*

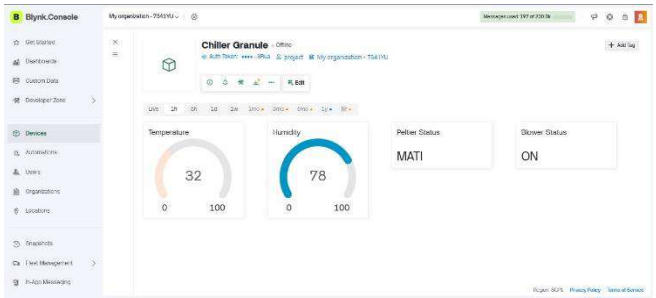



Fig. 10. IoT Dashboard Display

The test results show that the IoT system based on the Blynk application is capable of performing real-time temperature and humidity monitoring. Data from the sensors were successfully transmitted and displayed properly in the application, allowing users to monitor system conditions remotely. The system was also able to respond automatically to environmental changes. When the temperature exceeded the desired value, the system activated the cooling mechanism, whereas when the temperature approached the target value, the cooling operation was reduced or turned off. Under high humidity conditions, the system automatically activated the fan to assist the drying process. To monitor temperature parameters using the

DHT11 temperature sensor, which provides simultaneous readings for temperature and air humidity. The integration between the Ds18B20 sensor and the DHT11 provides comprehensive monitoring [17].



Fig. 11. RPM Testing

Based on the test results, the fan rotational speed increased as the supplied voltage increased. Under maximum operating conditions, the fan operated at a voltage of 10 V with a current of 0.53 A and produced a rotational speed of 5027 rpm. This indicates that the fan is capable of generating sufficient airflow to effectively assist the granule drying process.

Overall, the IoT integration in this system operates effectively, as demonstrated by the system's ability to perform remote monitoring, automatic decision-making, and maintain stable conditions according to the predetermined parameters.

## IV. CONCLUSION

Based on the results of the design, implementation, and testing of the Raspberry Pi-based chiller prototype using the fuzzy logic method, several conclusions can be drawn as follows:

1. The Raspberry Pi-based chiller system using fuzzy logic was successfully able to operate automatically in regulating temperature.
2. The Peltier TEC1-12706 module operated according to the conditions, namely at maximum level when the temperature was high, at medium level when the temperature was moderate, and turned off when the temperature reached normal conditions.
3. The blower fan was activated when the humidity exceeded 70% and turned off when the humidity was $\leq$ 70%.
4. The sensors demonstrated good accuracy, with the DS18B20 sensor having an error of approximately ±0.89% and the DHT22 sensor having an error of approximately ±3.33%.
5. The test results showed that the blower operated at 10 V, 0.53 A, and 5027 rpm, while the Peltier TEC1-12706 module operated within a voltage range of approximately 7.3–10.2 V with a current of 3.55 A.
6. The IoT system based on the Blynk application operated properly for real-time and remote monitoring.

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