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Design of a Rice Drying System Prototype Based on PLC Simatic S7-1200

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Abstract

Rice drying in Indonesia generally still uses conventional methods by utilizing sunlight. However, weather changes often become obstacles, hampering the drying process. This research designed an automatic rice dryer based on PLC that uses PLN electricity as a power source and a heater as the heating element. The system is equipped with a sensor to monitor the moisture content of the rice so that the heater automatically turns off when the rice is dry. A DC motor is used as a drive to move the rice during the drying process. PLC programming is carried out using TIA Portal software with ladder diagram language. Based on testing for 33 minutes, the drying temperature increased from 30.7°C to 33.29°C, while the moisture content of the rice decreased from 21.20% to 13.54%, and the rice weight decreased from 1000g to 919g. These results indicate that the PLC-based drying system can control the rice drying process in a stable and effective manner. This tool is expected to be widely implemented on an agricultural scale to improve rice quality efficiently and reduce dependence on unpredictable weather conditions.

Keywords: *rice dryer, PLC, TIA PORTAL, rice moisture content*

Abstrak

Pengeringan gabah di Indonesia umumnya masih menggunakan metode konvensional dengan memanfaatkan sinar matahari. Namun, perubahan cuaca sering menjadi kendala sehingga proses pengeringan terhambat. Penelitian ini merancang alat pengering gabah otomatis berbasis PLC yang menggunakan sumber listrik PLN dan heater sebagai pemanas. Sistem dilengkapi sensor untuk memantau kadar air gabah, sehingga heater akan otomatis padam ketika gabah telah kering. Motor DC digunakan sebagai penggerak untuk memindahkan gabah selama proses pengeringan. Pemrograman PLC dilakukan menggunakan software TIA Portal dengan bahasa ladder diagram. Berdasarkan hasil pengujian selama 33 menit, suhu pengering meningkat dari 30,7°C menjadi 33,29°C, sedangkan kadar air gabah menurun dari 21,20% menjadi 13,54%, dan berat gabah berkurang dari 1000g menjadi 919g. Hasil ini menunjukkan bahwa sistem pengering berbasis PLC mampu mengendalikan proses pengeringan gabah secara stabil dan efektif. Diharapkan, alat ini dapat diimplementasikan secara luas pada skala pertanian untuk meningkatkan mutu gabah secara efisien serta mengurangi ketergantungan terhadap cuaca yang tidak menentu.

Kata Kunci: *pengering gabah, PLC, TIA PORTAL, kadar air gabah*

1. Introduction

Indonesia is an agrarian country where most of its population earns a living as farmers. For most people in developing countries like Indonesia, agriculture is their only source of income[1]. Among these food farmers were rice farmers[2]. Rice (Oryza sativa L.) is one of the important food crops for most of the world's population, especially in Indonesia. The annual increase in population demands an increase in rice production to meet the food needs of the community[3]. Rice production in 2024 is 53.14 million tons of GKG, a decrease of 838.27 thousand tons or 1.55 percent compared to rice production in 2023, which was 53.98 million tons of GKG[4]. Indonesia's large rice production is indeed one of the important factors in the country's economy and food security[5].

Rice that has been harvested must undergo several processing stages before it can finally be consumed by the community. Rice milling is the process of processing paddy into rice[6]. The processing of rice into grain generally produces 72% rice, 5-8% bran, and 20-22% husks[7]. Generally, rice is harvested three times a year. To avoid damage and shrinkage, storage stages are required[8]. Therefore, drying is carried out to prevent damage to the rice. Drying is the process of removing a certain amount of water contained in a material. The drying process of rice aims to facilitate packaging, extend shelf life, and improve product quality. Generally, rice drying is carried out until the moisture content reaches 13% -

14%[9]. There are 2 different methods of drying rice, namely natural drying and artificial drying. Natural drying (traditional) is drying by spreading rice under sunlight, while artificial drying (mechanical) is drying using a drying machine[10].

Manual drying methods such as sun drying are still widely used among Indonesian farmers, but these methods have drawbacks such as dependence on weather and inconsistency in results[11]. Climate change, manifested thru shifts in temperature patterns, rainfall patterns, and the increasing frequency of extreme weather events, has heightened threats to agricultural productivity and, consequently, global food security[12]. One way to assist farmers in the rice drying process is by using a rice drying machine that can dry the grains without being affected by the weather[13]. Challenges such as climate change and population growth necessitate innovation in agricultural practices to improve productivity and resource use efficiency[14]. Related research has developed an automatic rice drying machine with temperature control using microcontrollers and PLC, improving the efficiency and consistency of the process[15]. In the study (Rais et al., 2022), a PLC-based Rice Dryer with a temperature sensor was developed, with 25 Kg of rice shows that the reduction from the initial moisture content of 49% to the final moisture content of 15% was dried in a dryer for 45 minutes at a temperature of 40°C[16].

Generally, humans need technology to improve performance or productivity, resulting in more optimal outcomes[17]. With the advancement of technology, automation in agricultural processes is becoming increasingly relevant to enhance efficiency and productivity[18]. This article offers a solution in the form of using simple technology, such as automation machines[19]. Modern rice drying systems have adopted various technologies, one of which is the use of Programmable Logic Controllers (PLC)[20]. PLC offers advantages in terms of programming flexibility, operational reliability, and the ability to integrate various sensors and actuators, enabling more precise and adaptive drying process control to environmental conditions[21]. However, the development of a rice drying system prototype that is comprehensively integrated with the Simatic S7-1200 PLC, capable of responding to various environmental and rice parameters in real-time, still requires further study. Barriers such as high initial investment costs and immature infrastructure were also examined, along with ways to overcome them thru supportive policies and technological innovation[22].

Therefore, this research focuses on the design and development of a rice drying system prototype based on the Simatic S7-1200 PLC. This prototype is expected to optimize the rice drying process with automatic control of temperature, humidity, and airflow, resulting in high-quality rice with better energy efficiency. Thus, it is expected to provide innovative solutions to the post-harvest challenges of rice in Indonesia, enhance the added value of agricultural products, and support agricultural sustainability[23]. Expected outcomes include guidance for policymakers and industry players in developing more effective sustainable strategies, as well as increased public awareness and support for the importance of this integration for a more prosperous and sustainable future for Indonesia[24].

2. Material and Methods

Research Methodology

This research requires planning so that the results obtained meet the desired targets and objectives, thus steps have been planned in the preparation of this research. The flowchart illustrating the research methodology in this study can be found in **Figure 1**.

The flowchart illustrates a systematic process for designing and evaluating a tool or system. The process begins at the Start point and proceeds to the Design of the Tool stage, where the tool's physical and functional structure is developed. Once the design is completed, the process continues to the Program Planning phase, which involves writing the software or logic program that controls the tool’s operation—typically done using a programmable logic controller (PLC) in industrial applications.

After programming, the tool undergoes a Tool Test, where its functionality is checked against design expectations. If the tool fails this test, the process loops back to the initial design stage to revise and improve the system. If the tool functions correctly, the process moves forward to Data Collection, where performance data is gathered for analysis. This information is crucial for assessing the reliability and efficiency of the tool in practical scenarios.

Following data collection, the next stage is Conclusion, where results are analyzed and final insights or evaluations are made regarding the tool's effectiveness. The process is then finalized at the End, signifying the completion of the design, implementation, and assessment cycle. This flowchart reflects an iterative engineering approach that emphasizes continuous improvement and validation through testing and feedback. The research findings are documented in the form of a scientific article intended for publication in an indexed journal [25].

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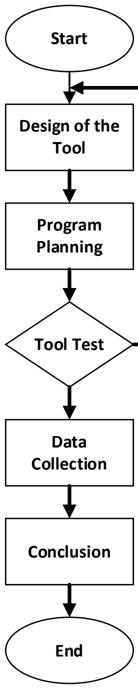

Fig. 1: Flowchart of the research methodology conducted
Source: Personal document

Designing Tools

The stages of tool design are the stages of designing the working system of the tool and selecting the components to be used. The block diagram of the working system of the rice dryer is shown in **Figure 2**.

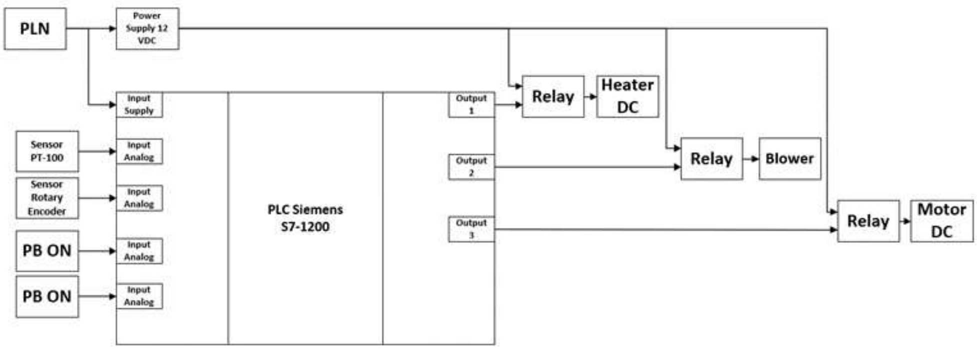

Fig. 2: Block diagram of the rice dryer system
Source: Personal document

The working principle of the block diagram of this rice drying system uses the Siemens Simatic S7-1200 PLC as the central automation controller with a main power source of 220VAC supplied through a power supply. The system input consists of a PT100 temperature sensor to detect the drying room temperature, a rotary encoder to measure the stirring motor speed, and ON and OFF push buttons as manual inputs. Data from the sensors are processed by the PLC based on the ladder diagram program, where the PLC will activate the heater through a relay if the temperature has not yet reached the set point of 34°C, and control the blower to circulate hot air and the DC stirring motor to ensure the rice is evenly stirred. The motor speed is monitored by the rotary encoder, allowing the PLC to adjust it according to the process requirements. With this system, the rice drying process runs automatically, efficiently, and results in quick and even drying.

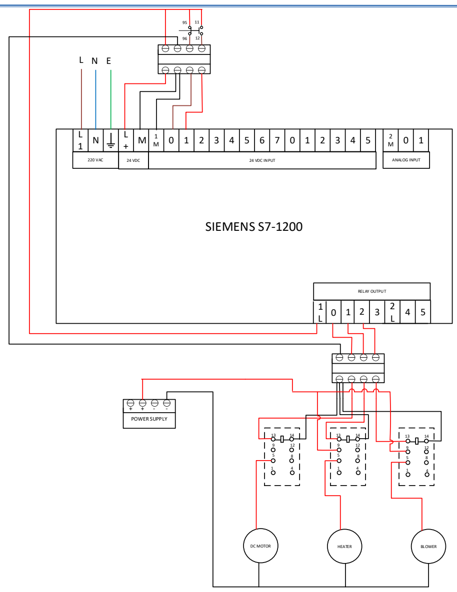

Fig. 3: Block diagram of the rice dryer system
Source: Personal document

After understanding the working system of the tool, the wiring diagram shown in **Figure 3** can be determined. Meanwhile, the materials used as components in the making of the blood glucose measuring tool are shown in **Table 1**.

Table 1. Materials needed to make a rice drying tool

Materials	Quantity
Inpari 30 rice variety	As needed
PLC Simatic S7-1200	1
Push button	2
12V air heater	1
12V DC gearbox motor	1
12V DC mini fan blower	1
4 Pin terminal block	3
MY2N relay	2
Moisture sensor	1
Thermocouple temperature sensor	1
12V power supply	1
Tachometer	1
Rotary encoder	1
PT-100 temperature sensor	1
Transmitter	1
Cable	As needed

Source: Personal document

Moisture Content of Paddy

The characteristics of the physical quality of milled dry rice grains of irrigated paddy, upland rice, and hybrid varieties planted in the BB Padi MK 2014 Experimental Garden are presented in **Table 2**. Water is the main component of food that is responsible for the rate of deterioration during the storage period. High moisture content in rice increases the rate of damage both enzymatically and hydrolytically. Additionally, high moisture content in rice increases the infestation of warehouse pests, especially Sitophilus Oryzae.

The moisture content requirement for paddy/rice for storage purposes is a maximum of 14% (SNI 2008). The data in **Table 2** shows the moisture content of milled rice from all analyzed rice varieties ranging from 10,5% (Inpago 5) to 14,4% (Ciherang and Inpari 16) with an average of 12,72%, which is less than 14%, falling into the safe category for storage [26].

Table 2. Physical characteristics of rice quality

Variety	Moisture Content (%)	Density (g/l)	Gang (%)	Green/Chalk (%)
Ciherang	14,4	522	1,91	4,06
Situ Bagendit	13,1	503,5	1,08	4,15
Cibogo	12,6	527	1,04	3,06
Batu Tegi	13,3	500	3,25	4,55
Hipa Jatim 1	13,25	493,5	3,2	9,61
Hipa Jatim 2	12,85	487,75	1,43	4,27
Hipa Jatim 3	13,14	505,5	3,6	2,47
Hipa 8	13,37	467,6	3,55	4,72
Hipa 18	13,15	492	2,58	3,47
Inpago 5	10,55	502	0,91	2,6
Inpago 7	11,45	503	2,5	5,75
Inpago 8	11,1	524	2,8	4,12
Inpari 10	12,25	512	1,5	2,17
Inpari 13	11,3	495,2	4,86	5,5
Inpari 14	12,32	516	1,08	2,24
Inpari 16	14,4	517	1,95	4,42
Inpari 30	13,67	514,2	4,21	6,22
Rata-rata	12,72	504,84	2,27	4,32

Source: Balai Penelitian Tanaman Padi Sukamandi

Another component of the physical quality of rice is the level of empty grains/impurities. This characteristic, along with its density value, determines the yield of milled rice obtained. Practically, the measurement of these two characteristics in the field is done manually by grasping a handful of rice grains, then squeezing and releasing them. If it feels heavy in the hand, it is estimated that the rice yield produced is high, and vice versa.

Analysis Method

1) Drying Rate Analysis Method

The drying rate is the decrease in moisture content of the wet basis of the rice grains per unit of time. It is measured by checking the moisture content every 1-hour interval.

$$LP = \frac{Ka\ Mg\ in - Ka\ Mg\ out}{t}$$

Information:

LP = Drying Rate per Hour (%/hour)
$Ka\ Mg\ in$ = Moisture content of paddy before drying (%)
$Ka\ Mg\ out$ = Moisture content of paddy after drying (%)
t = Time required to reduce moisture content (hours)

2) Drying Power Analysis Method

The Drying Power Analysis Method is an approach or technique used to calculate and evaluate the electrical energy (kWh) requirements used in the rice drying process.

$$E = P \times DT \text{ [27]}$$

Information:

E = Energy (kWh)
P = Power (W)
DT = Drying time (minute)

3) Drying Cost Analysis Method

The analysis of drying costs is the product of the power of the drying equipment (Kwh) multiplied by the price per Kwh (Rp/kWh).

$$Bx\% = \frac{PP \times Costkwh}{Mg\ in} \text{ [28]}$$

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Information:

$Bx\%$	= Drying cost (Rp/ Kg)
PP	= Total power of the equipment during drying (kWh)
$Costkwh$	= Electricity price (Rp/kWh)
$Mg\ in$	= Dried paddy mass (Kg)

3. Results and Discussion

Hardware Rice Dryer

Hardware the rice dryer is the physical form that has been successfully created, as shown in **Figure 4**.

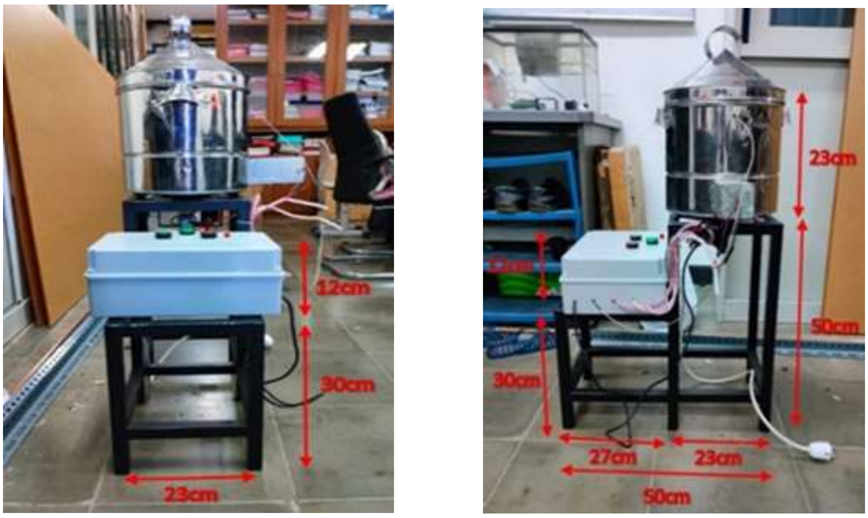

Fig. 4: Front view (left side) and right view (right side) of the rice drying machine
Source: Personal document

This rice drying machine consists of a leg construction and a drying tube. The legs are made from hollow iron, 50 cm high and 23 cm wide, with a sturdy open box design to support the drying tube and facilitate the arrangement of cables and components. The drying tube uses an aluminum or stainless steel pot with a diameter and height of 23 cm as the main chamber for placing the rice, chosen for its good heat conductivity and high-temperature resistance. Under the tube, a DC motor coupled with a rotary encoder sensor is installed to rotate the rice so that the heat is evenly distributed and to prevent clumping, while the encoder sends data to the PLC to control the motor speed. On the side of the tube, there is a small box containing a DC heater as the main heat source with a set point of 34°C and a mini fan DC blower to evenly distribute the hot air. With this design, the rice drying system operates automatically, stably, efficiently, and produces optimal dried rice quality in accordance with the research objectives.

General Drying Data

General drying data is the most basic data that can be used to determine the drying rate. This data includes important technical parameters for the design and operation of rice drying equipment.

Table 3. General Drying Data

E	Mg in (g)	Mg out (g)	Ka Mg in (%)	Ka Mg out (%)	DT
1	1000g	942g	21,2%	19,77%	9min
2	942g	934g	19,77%	16,7%	9min
3	934g	923g	16,7%	13,81%	9min
4	923g	919g	13,81%	13,54%	6min

Source: Personal document

Information:

E	= Experiment
Mg in	= Initial mass of paddy/ entering the machine (g)
Mg out	= Dry paddy mass/output from the machine (g)
Ka Mg in	= Initial moisture content of paddy (%)

Ka Mg out = Moisture content of dry rice husk (%)
DT = Drying time (minute)

Drying Rate Analysis (LP)

Drying Rate Analysis is a process to determine how quickly the water contained in rice (or other materials) evaporates during the drying process.

Table 4. Drying rate

E	Ka Mg in (%)	Ka Mg out (%)	DT	DR
1	21,2%	19,77%	9min	0,158
2	19,77%	16,7%	9min	0,341
3	16,7%	13,81%	9min	0,321
4	13,81%	13,54%	6min	0,045
Avg				0,21

Source: Personal document

Information:
E = Experiment
Ka Mg in = Initial moisture content of paddy (%)
Ka Mg out = Moisture content of dry rice husk (%)
DT = Drying time (minute)
DR = Drying rate (%/minute)
Calculation from the table above:

$$DR = \frac{21{,}2 - 19{,}77}{9} = 0{,}158\%/minute$$

Drying Power Analysis

The analysis of drying power is the total power used by the equipment during the rice drying process, measured in Kwh. Drying was carried out for 33 minutes or 0,55 hour, and the moisture content of the rice decreased significantly from 21,20% to 13,54%. This indicates that the drying system is capable of reducing the moisture content of the rice to meet the drying standard for the inpari 30 variety, which has a drying moisture standard of 13,67%. According to the Siemens S7-1200 PLC datasheet, the PLC has a power consumption of 120mA at 240VAC. Power consumption is the amount of electrical energy used by a device to perform its function [29].

Table 5. Drying Power

Component	V	A	P	DT	E
PLC Siemens S7-1200	240V	0,12A	28,8W	0,55 hour	15,84Wh
Heater	12V	8A	96W	0,55 hour	52,8Wh
Motor DC	12V	0,067A	0,804W	0,55 hour	0,442Wh
Blower mini fan DC	12V	0,069A	0,828W	0,55 hour	0,455Wh
Total			126,432W		69,537Wh

Source: Personal document

Information:
V = Volt
A = Ampere
P = Power
DT = Drying time (hour)
E = Energy (Wh)
Calculation from the table above:

$$E = 28{,}8 \times 0{,}55 = 15{,}84Wh$$

Drying Cost Analysis

Drying Cost Analysis is the process of calculating the total electricity cost incurred to operate the rice drying system. The electricity consumption obtained previously was 69,537Wh or equivalent to

0,069537kWh. The drying process lasted for 0.55 hours. According to data from Permen ESDM No. 7 of 2024, the electricity tariff per kWh for business purposes is Rp 1444,70[30].

$$Bx\% = \frac{0{,}069537 \times 1444{,}7}{1} = 100{,}46$$

From the above calculation, it is obtained that to dry 1kg of rice with a moisture content of 21,2% for 0,55 hours, at an electricity cost of Rp 1444,70 per kWh, it requires a cost of Rp 100,46 / kg.

4. Conclusion

The rice drying process successfully reduced the moisture content from 21,20% to 13,54% in 33 minutes. This reduction indicates that the drying system is capable of lowering the moisture content of the rice to meet the drying standard of the Inpari 30 variety, which has a drying moisture content standard of 13.67%. The highest drying rate reached 0,341%/minute, with an average of 0,21%/minute, indicating that the process was stable and efficient. The system uses a total power of 126,432 Watts with an energy consumption of 69,537Wh (0,069537 kWh) during operation. With an electricity tariff of Rp 1444,70/kWh, the drying cost for 1 kg of paddy is only Rp 100,46; making this system energy-efficient and economical for small to medium scales.

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6. Abbreviations

GKG	Dry Milled Rice
%	Percentage
kWh	Kilowatt-hour
Wh	Watt-hour
kg	Kilogram
DC	Direct Current
C	Celcius

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