APPLICATION OF FUZZY LOGIC CONTROL SYSTEM IN HYBRID ELECTRIC AND SOLAR ENERGY RACK-TYPE DRYER

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AGRICULTURAL ENGINEERING STUDY PROGRAM
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ABSTRACT

The background of this research is that the rack type dryer is one of the artificial dryers designed to overcome the weaknesses of the direct drying method. But artificial dryers require a large amount of energy to dry agricultural materials. The purpose of this research is to produce a fuzzy logic control system, as well as the control performance of the rack type dryer with electric and solar hybrid energy. The research method was carried out by studying the parts of the tool, creating a control program, then testing the functional and performance of the dryer using wet sago. The results of the analysis of the functional test of the drying machine with hybrid and non-hybrid energy show that the control system works well, namely the relatively small settling time of 12 minutes, a small steady state error of 1°C and not overshoot. The results of the analysis of the performance test using electrical energy (non-hybrid) with sago material with an initial moisture content of 44.65% wb showed an average drying rate of 0.037kg / kg hour, and the drying process took 4.5 hours. While the performance using hybrid energy with sago material, the initial moisture content of 46.48% wb shows an average drying rate of 0.036kg / kg hour, and the drying process takes 5 hours. The electrical energy used with the non-hybrid system is 5.32kWh, while the hybrid system is 2.55kWh. The application of the hybrid system can save electricity by 52.07% and the resulting sago water content is in accordance with the SNI target: 3729-2008 maximum of 13% wb.

Keywords*: Dryer, energy hybrid, and fuzzy logic*

STATEMENT OF THESIS AUTHENTICITY

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Stating with truth that the thesis I wrote is really my work, not an appropriation of other people's writings or thoughts. is really my work, not a takeover of other people's writings or thoughts. If in the future it is proven or can be proven that part or all of this thesis is the work of others, I am willing to accept sanctions for these actions.

Makassar, March 2021

Who declares

ARAFAH

LIFE HISTORY

Arafah was born in Maros on April 25, 1997, the fourth of four children of Mr. H. Sele and Hj. Sennari.

The levels of formal education that have been passed are:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ATTACHMENTS

1. INTRODUCTION

1.1. Background

Drying agricultural materials is an effort made to remove the water content from the material. The most common drying method is by drying the material directly under the sun. However, there are many disadvantages to the drying method, for example, the need for large areas of land, easy contamination and erratic sunlight due to weather changes.

The rack-type dryer is one of the artificial dryers designed to overcome the disadvantages of the direct drying method. But artificial dryers require large amounts of energy to dry agricultural materials. Rack-type dryers are currently found using solar energy or electrical energy (Amelia, 2007). Solar energy is a renewable energy whose availability will not run out, but because solar energy is erratic (fluctuating), the heat in a dryer that uses a solar collector is relatively unstable. Electrical energy is an energy whose availability is continuous (not fluctuating), so the heat in the dryer is relatively stable, but the use of electrical energy requires expensive costs in its application.

To produce a dryer that performs well and is energy efficient, it is necessary to use hybrid solar energy with electricity, but combining two energy sources in a system can cause the system to be non-linear, uncertain or fuzzy. According to Jager (1995), the application of control systems to non-linear systems can be done using intelligent systems. One of the intelligent systems that has been proven to control the system well is a fuzzy logic system.

Based on this, research has been carried out on the design of a fuzzy logic control system on a rack-type dryer.

1.2. Problem Formulation

The formulation of the problem in this research is:

1. What are the appropriate fuzzy logic control rules for hybrid electric and solar energy rack-type dryers?
2. How is the performance of the fuzzy logic control system on a hybrid electric and solar energy rack-type dryer?

3. Does the moisture content of the dried material meet SNI 3729: 2008?

1.3. Purpose and Usefulness

The purpose of this research is to produce a fuzzy logic control system, and determine the performance of the control system on a rack-type dryer with hybrid electric and solar energy.

The usefulness of this research is to be the main alternative for users of energy-efficient dryers and to be a reference material in further development and research on controlled dryers.

1.4. Problem Limitation

The problem limitations in this study are:

1. The fuzzy logic control system applied uses Sugeno fuzzy inference.
2. The test sample used in this research is wet sago flour.
3. Sago flour was dried to a maximum uniform moisture content of 13% wt% (SNI 3729:2008).

2. LITERATURE REVIEW

2.1. Drying

Drying is an effort to reduce the water content of the material. The material becomes dry due to evaporation into the air due to the difference in water vapor content between the air and the dried material. As a result reduced water content will cause the development of microorganisms and enzyme activities that can cause decay to be inhibited or even stopped altogether, thus the dried material has a longer shelf life. Drying of materials can be done in two ways, namely drying directly in the sun or by using a dryer (Irfan, 2015).

Conventional drying by drying materials under the hot sun has the advantage of not requiring greater costs and the capacity of dried materials is not limited. However, conventional drying has a drawback, namely the drying place is not clean for food, because it is in an open area. Fluactive heat can reduce dried food. In addition, using direct sunlight, temperature and humidity that cannot be controlled can reduce the quality of the material being dried and also the time required requires a long time. Meanwhile, by using a drying machine, the time required is shorter and of higher quality, and the temperature is under control. Drying also does not depend on climate and weather (not necessarily during the day but can also be at night) (Irfan, 2015).

2.2. Observation Parameters

The parameters that affect the drying time of food include (Irfan, 2015):

2.2.1. Dryer Air Temperature

The temperature of the dryer air affects the water evaporation rate of the material and the quality of drying. The higher the temperature, the shorter the drying time, but so that the dried material is not damaged by high temperatures, the temperature needs to be controlled. Raising the temperature in the drying chamber requires energy from the heater. The energy formula for raising the air temperature using a heater can be used equation (2.1) (Singh, 1984):

$$Q = \dot{m} \text{ x } C_p \text{ x } (T_2 - T_1) \tag{2.1}$$

Explanation::

Q = energy for heating the drying chamber (J/jam)

ṁ = air mass velocity (kg/jam)

C_p = specific heat of air (J/kg^{o}C)

T_1 = air temperature before passing through the heater (^{o}C)

T_2 = air temperature after passing through the heater (^{o}C

2.2.2. Relative Humidity (RH) of Dryer Air

Relative humidity determines the ability of dryer air to hold material water that has been evaporated. If the RH is low, the more moisture the dryer air absorbs, and vice versa. The RH and temperature of the dryer will determine the saturated vapor pressure. The difference in water vapor pressure in the drying air with the surface of the material will affect the drying rate.

2.2.3. Aliran udara pengering

Relative humidity determines the ability of dryer air to hold material water that has been evaporated. If the RH is low, the more moisture the dryer air absorbs, and vice versa. The RH and temperature of the dryer will determine the saturated vapor pressure. The difference in water vapor pressure in the drying air with the surface of the material will affect the drying rate. To drain hot air into the drying room, you can use a blower, the larger the blower, the greater the incoming airflow discharge, by knowing the amount of airflow discharge needed for drying, it can know the size of the blower used in the tool. To calculate the airflow discharge required in the drying process, equation (2.2) can be used. To calculate the mass flow speed of drying air, equation (2.3) can be used (Arun, 2008):

$$Q = W_{up} \text{ x } \rho \quad (2.2)$$

$$W_{up} = \frac{V}{H_2 - H_1} \quad (2.3)$$

$$V = \frac{M_a}{t} \quad (2.4)$$

$$M_a = m \frac{M_{1-} M_2}{100 - M_2} \quad (2.5)$$

Explanation:

Q = air flow (m^3/s).

Wup = dryer air requirements (kg/s)
H1 = absolute humidity of air at first (kg/kg dry air)
H2 = absolute humidity of air when drying (kg/kg dry air)
V = drying velocity (kg/s)
Ma = weight of evaporating water (kg)
m = weight of dryed material (kg)
M1 = initial moisture content (%)
M2 = final moisture content (%)
t = drying time (s)
ρ = Specific weight of air (m^3/kg)

2.2.4. Moisture Content Material

Water content is the amount of water contained by materials, both free and bound water. The moisture content of a material can be expressed in two ways, namely the moisture content of the wet base (m) and the moisture content of the dry base (M). The moisture content of the wet base has a theoretical maximum limit of 100%, while the moisture content of the dry base can be more than 100%. To calculate the moisture content used the following equations (2.6) and (2.7):

$$m = \frac{W_m}{W_m + W_d} \times 100\% \quad (2.6)$$

$$M = \frac{W_m}{W_d} \times 100\% \quad (2.7)$$

Explanation:
m = moisture content of wet base (%)
M = moisture content of dry base (%)
Wm = weight of material (g)
Wd = weight of solid (g)

2.2.5. Equilibrium Moisture Content

Equilibrium moisture content is defined as the water content of a material that is in balance with the water content of the surrounding air, or the minimum moisture content achieved under fixed drying air conditions.

2.3. Rack-Type Dryer

Rack-type dryers with electric energy have two chambers, namely the heating room and the drying room. The working principle of the rack-type dryer using electrical energy is that the hot air from the heating chamber is pumped into the drying chamber. The airflow is regulated by the steering chamber in the direction of the drying chamber. Air with high moisture content is directed outward by the directional chamber to the outside of the dryer. The heating process in rack-type dryers occurs through the jetting of hot air on each rack (Hardanto, 2009).

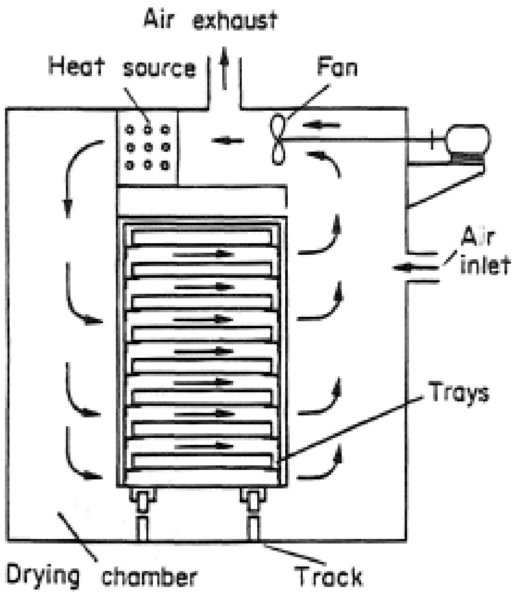

Figure 2.1 Scheme of rack-type dryer
(Source: Hardanto, 2009).

2.4. Sago Flour Drying

Drying flour is an important process because the moisture content in flour is much lower when compared to the basic ingredients. In research conducted by Saripudin (2006), the drying process in sago flour uses the moisture content of the material as a benchmark. Drying is carried out to determine the drying characteristics of sago flour so that the moisture content of the dry base is 6%. At 6% dry base, moisture content can extend the shelf life of sago flour and maintain the quality of sago flour. In his research, 60ºC and 70ºC drying temperatures were chosen, arguing that the initial gelatinization temperature of sago starch was around 72ºC (Saripudin, 2006).

Based on the Indonesian National Standard (SNI) regarding the quality standard of sago starch then issued by the National Standardization Agency (BSN) in 2008, as seen in Table 2-1.

Table 2-1. Quality Requirements for Sago Starch

Criteria	SNI 3729:2008	
	Unit	**Requirement**
1. Parameters		
1.1. Smell	-	Normal
1.2. Color	-	White, typical of sago
1.3. Taste	-	Normal
1.4. Shape	-	Powder
2. Foreign object	-	None
3. Insects (in all forms of stadia and pieces)	-	None
4. Other types of starch besides sago starch	-	None
5. Moisture content	% (b/b)	Max 13
6. Ash content	% (b/b)	Max 0,5
7. Starch content	-	Min 65
8. Crude fiber content	% (b/b)	Max 0,5
9. Degree of acid	ml NaOH 1N/100g	Max 4,0
10. SO_2 Residu	mg/kg	Max 30
11. Food additives (bleaching agents)	-	SNI 01-0222-1995
12. Smoothness, pass sieve 100 mesh	% (b/b)	Min 95
13. Metal contamination		
13.1. Lead (Pb)	mg/kg	Max 1,0
13.2. Copper (Cu)	mg/kg	Max 10,0
13.3. Mercury (Hg)	mg/kg	Max 0,05
14. Arsen (As)	mg/kg	Max 0,50
15. Microbe contamination	Colony/g	Max 10^6
15.1. Total slab number	APM/g	Max 10
15.2. E.coli	Colony/g	Max 10^4
15.3. Mold		

Source: SNI 3729:2008.

2.5. Electric Furnace

An electric furnace is a furnace that converts electrical energy into thermal energy. The transfer of energy in the furnace occurs in the stages of the generation of thermal energy by heating elements whose energy is supplied by electrical energy.

Where in this case there is a change in electrical energy into thermal energy (Yoga, 2018). The formula for calculating the power used in the heater is as follows:

$$P = V \times I \times Pf \tag{2.8}$$

$$P = I^2 \times R \tag{2.9}$$

Explanation:

P = power (W),

V = voltage at the terminals of the heating element (V),

Pf = factor Power r,

I = electric current passing through the heating element (A) dan

R = electrical resistance of heating elements (ohm).

2.6. Solar Energy

Solar energy is one form of renewable alternative energy that can be used to replace energy produced by petroleum. The use of solar energy also does not cause pollution that can damage the environment. Solar energy in agriculture can be used for drying. One way to absorb solar energy and convert it into heat is to use solar collectors (Arikundo et al, 2014).

2.7. *Fuzzy Logic* System

Fuzzy logic systems are structured and dynamic numerical interpreters. The system infers a function with fuzzy logic. Several things need to be known in understanding fuzzy logic control systems, namely the function of fuzzification, inference, implication and defuzzification (Cirstea et al, 2002).

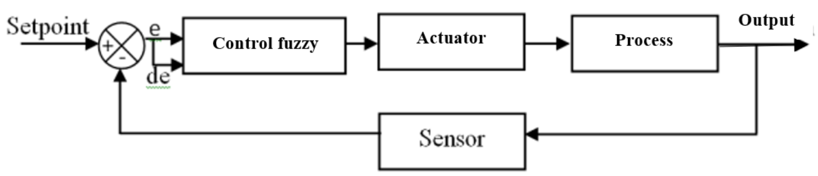

Figure 2.2. Fuzzy logic control system block diagram.
(Cirstea et al, 2002).

2.7.1. *Fuzzification*

Fuzzification is the process required to convert non-fuzzy crisp inputs into fuzzy values from several defined input linguistic variable values (Cirstea et al, 2002).

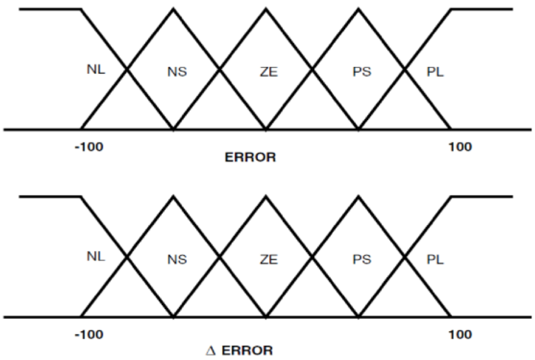

Figure 2.3. Fuzzification error and delta error with 5 membership functions (Cirstea et al, 2002).

2.7.2. Membership Functions

The membership function is a curve that shows the mapping of data input points into their membership values (membership degrees) that have an interval between 0 and 1. One way that can be used to get membership value is through the value function approach. Some commonly used functions, namely triangle, trapezium, Gaussian, and bell. In the control of membership functions that are often used is the triangular model (Cirstea et al, 2002).

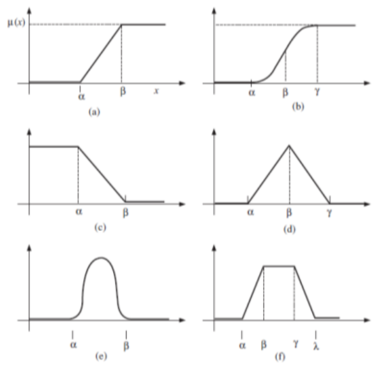

Figure 2.4. Membership functions (Cirstea et al, 2002).

2.7.3. Fuzzy Inference

The fuzzy inference system using the Sugeno method has the characteristic that the fuzzy output is not a fuzzy set but is a linear equation with variables according to the input. Here is a fuzzy model of the Zero-Order Sugeno:

IF (x1 is A1) • (x2 is A2) • (x3 is A3) • ...... • (xN is AN) THEN z=k

With Ai is i-th fuzzy set as a condition, ● is a Fuzzy operator (such as AND or OR), and k is a constant as an action.

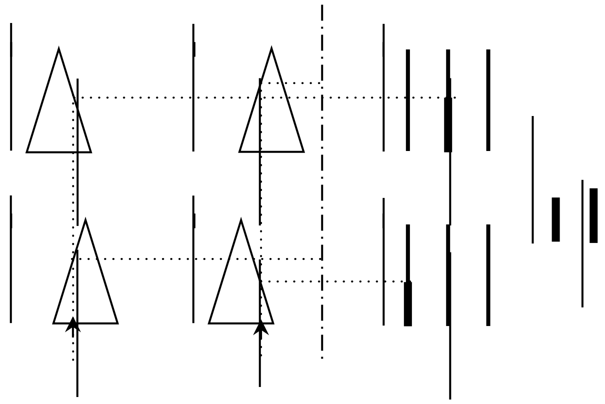

Figure 2.5. Sugeno fuzzy inference
(Cirstea et al, 2002).

2.7.4. Implication

Implication is the process of getting an action or output from an IF-THEN rule. The following is an example of the syntax (Yan, 1994):

IF (y1 is A) AND (y2 is B) THEN (z is B)

IF (y1 is A) OR (y2 is B) THEN (z is B)

Explanation:

y1 is A, y2 is B	= premise, or condition.
z is B	= consequent, conclusion, or action
A, B	= linguistic values (hot, warm, cold, etc.)
AND	= minimum function.
OR	= Maximum function.

2.7.5. Defuzzification

The input or input of the defuzzification process is a fuzzy set obtained from the composition of fuzzy rules that have been arranged, while the output produced is a number in the domain of the fuzzy set. There are several defuzzification methods, including the center of gravity, the center of average, and the mean of maxima. The defuzzification formula for the center of gravity method is as follows (Jager, 1995):

$$y^* = \frac{\sum_i \mu(x_i)x_i}{\sum_i \mu(x_i)} \quad (2.10)$$

Explanation:

y* = Crisp-value control signals.

N = number of rules.

x_i = i-th position in the universe of speech.

$\mu(x_i)$ = membership degrees.

2.8. Control System

A control system is an arrangement of physical components that can command or direct the system to the tool. The control system in principle intends to define input-output and is used in the preparation of rules in the control system. System control always strives to get work results as expected, by minimizing or eliminating errors. The error is the result of a comparison between the setpoint value and the value read by the sensor (Jager, 1995).

X1 \ X2	P	Z	N
P	VS	S	M
Z	S	M	B
N	M	B	VB

Figure 2.6. Method of compiling control rules using matrices
(Source: Jager, 1995).

Explanation :

X1, X2 = Control input variables,

P,Z,N = Control input membership functions (positive, zero and negative),

VB,B,M,S,VS = Control output membership function (very big, big, medium, small, very small).

According to Bolton (2004), there are two known concepts in control systems, namely closed-loop or feedback control systems and open-loop control systems. The main components of the control system are:

a. *Setpoint*

Setpoints are setpoints in open and closed-loop control systems. Setpoints can be created by creating a voltage divider circuit. The output of the voltage divider is used as the voltage input for setpoint readings inside the microcontroller (Bolton, 2004).

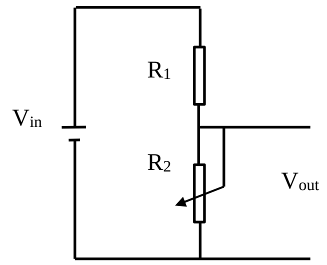

Figure 2.7. Voltage divider circuit.
(Source: Bolton, 2004).

The amount of voltage coming out of the voltage divider circuit (half bridge) can be calculated using the formula (Bolton, 2004):

$$V_{out} = \frac{R_2}{R_1+R_2} \times V_{in} \quad (2.11)$$

Explanation:

V_{in} = Inlet voltage (V).

V_{out} = Outlet voltage (V).

R_1 = resistor resistance (Ω).

R_2 = potentiometer resistance (Ω).

b. Microcontroller

Microcontroller is a microcomputer made in the form of a semiconductor chip that has three main components, a central processing unit, memory and an input/output system to be connected to external devices. Some microcontrollers already have ADC (Analog to Digital Converter) and PWM (Pulse Width Modulation). PWM is the control of the actuator by adjusting the width of the pulse sent to the actuator. The control signal is in the form of on and off signals. By adjusting the ratio of the length of the signal on or off given, changes can be obtained in the actuator (Irfan, 2015).

c. Actuator

The actuator is a mechanical drive to drive or control a mechanism in the system (Bolton, 2004).

d. Sensor

Sensors are the input of information to a computer system from the outside world. Systems with microcontrollers generally use input devices such as sensors (Bolton, 2004).

3. RESEARCH METHOD

3.1. Time and Place

This research was conducted in July 2019, at the UNHAS Faculty Housing Complex and the Agricultural Engineering Laboratory at Hasanuddin University, Makassar.

3.2. Tools and Material

The tools used in this study are a downloader, microcontroller, digital scale with a resolution of 0.01 grams, a kWh meter, and a laptop. The software used are Code Vision AVR, Matlab, and Microsoft Excel. The test material used in this study is wet sago flour.

3.3. Research Procedure

The research procedure is shown in the following flowchart:

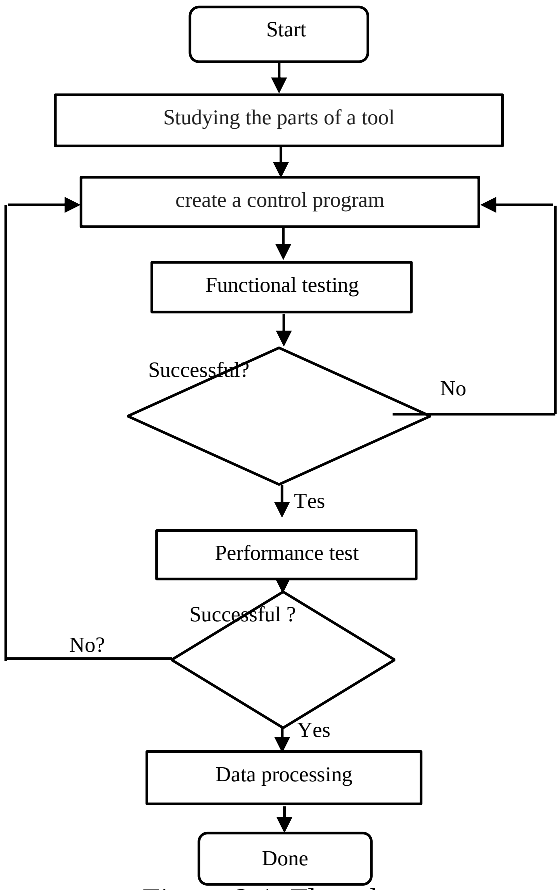

Figure 3.1. Flowchart

3.3.1. Studying the Parts of the Device

The initial step in this research was to study the parts of the device, with the goal of understanding the specifications, the operation of each component in the device, and to identify the system by performing a gain test.

The gain test is intended to determine if the power of the drying device can exceed the setpoint temperature that will be applied. The gain equation is as follows:

$$\text{Gain} = \frac{\Delta T}{\Delta t} \tag{3.1}$$

Explanation:

ΔT = Change in temperature (^{o}C).

Δt = Change in time (s).

3.3.2. Create a control program

To create a control program using fuzzy logic control with Sugeno fuzzy inference, the input and output of a hybrid solar and electric dryer must be determined. The procedure for creating the control program can be seen in the flowchart below:

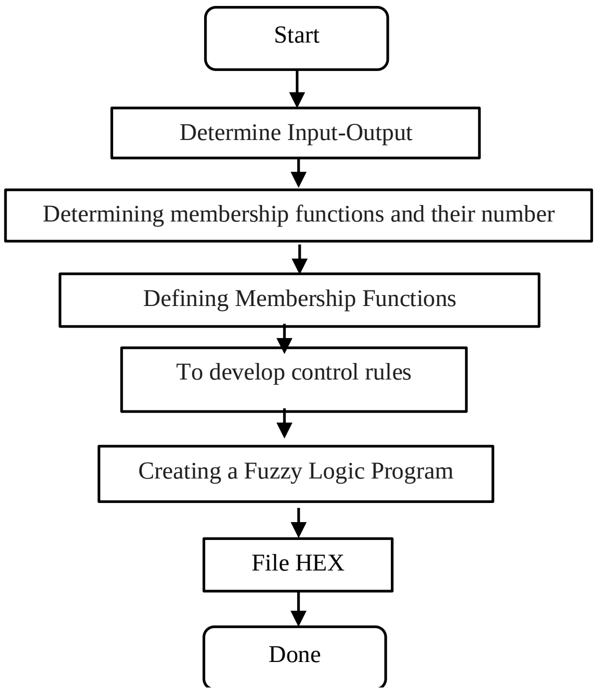

Figure 3.2. Flowchart of fuzzy logic control program creation

1. To determine the input-output, the purpose is to define the input and output values of the control. The input to the control system is the error value and the

delta error value resulting from the reading of the setpoint and temperature values, while the output is the control signal (PWM).

2. To determine the membership functions and their number, the input membership function used in this study is a triangle with 3 members. The output is singleton with 5 members.
3. To define the membership functions, the purpose is to determine the universe of discourse and its values. In this study, the universe of discourse for the input program control is error and delta error. The universe of discourse for the output program control is PWM.
4. In this study, the control rule used is the output target based on the error and delta error, with the purpose of avoiding overshoot and temperature instability. The rules are as follows:

de \ e	N	Z	P
N	VS	VS	M
Z	VS	VS	B
P	VS	S	VB

Figure 3.3 Matrix-based method of rule formulation

Explanation:

e,de = input variables (error, delta error)

P,Z,N = input control membership functions (negative, zero, and positive)

VS,S,,M,B,VB = output control membership functions (very small, small, medium, big, very big)

a. *IF* (*error is* N) *AND* (*delta error is* N) *THEN* (PWM *is* VS)
b. *IF* (*error is* N) *AND* (*delta error is* Z) *THEN* (PWM *is* VS)
c. *IF* (*error is* N) *AND* (*delta error is* P) *THEN* (PWM *is* VS)
d. *IF* (*error is* Z) *AND* (*delta error is* N) *THEN* (PWM *is* VS)
e. *IF* (*error is* Z) *AND* (*delta error is* Z) *THEN* (PWM *is* VS)
f. *IF* (*error is* Z) *AND* (*delta error is* P) *THEN* (PWM *is* S)
g. *IF* (*error is* P) *AND* (*delta error is* N) *THEN* (PWM *is* M)
h. *IF* (*error is* P) *AND* (*delta error is* Z) *THEN* (PWM *is* B)

i. *IF* (*error is* P) *AND* (*delta error is* P) *THEN* (PWM *is* VB)

5. create a fuzzy logic program based on existing rules.
6. The hex file is a control program file that has been compiled using Code Vision AVR.

3.3.3. Testing

3.3.3.1. Functional Test

Functional testing is used to determine whether the control program can work as expected. Functional testing is performed by dynamic response control testing. Dynamic response control testing is performed to see the response of the control system on the dryer. The criteria used to show the success rate of dynamic response control testing are as follows:

1. Small temperature overshoot (<5%).
2. Relatively short temperature settling time.

3.3.3.2. Performance Test

Performance testing to determine whether the control program can work according to the expected success indicators. Performance testing was performed using wet sago flour to see the moisture content of the resulting material and energy consumption in the dryer with 2 conditions:

1. Using electrical energy (non-hybrid) and
2. Using solar and electrical energy (hybrid).

The performance testing procedure is as follows:

1. Prepare the material, which is wet sago flour that has been known to be the initial moisture content.
2. Insert wet sago flour weighing 1 kg/rack into the dryer.
3. Insert a 50 g sample into a small container and place it on the top and bottom shelves.
4. Run the device and set the drying temperature (60 oC) using electrical energy (non-hybrid).
5. Record the temperature on the device every 2 minutes.

6. Every 30 minutes, record the electrical energy used and the sample in the small container is removed from the dryer and then weighed using a digital scale until the material reaches a uniform moisture content of 13% bb.

The formula for calculating the weight of the material equivalent to the expected moisture content (max. 13% db):

$$W = \frac{100\,\%}{100\%-13\%} \text{ x Wd} \quad (3.2)$$

Explanation:

W = Weight of the material (g)

Wd = Weight of the solid sample material (g)

1) Repeat procedures 1-6 using hybrid energy

2) Data processing.

The following are indicators of the success of a drying machine using wet sago flour as a test material:

1. The final moisture content of sago flour is a maximum of 13% (wet basis, SNI 3729:2008).
2. Hybrid drying machines can save electricity consumption.

3.3.4. Data Processing

3.3.4.1. Moisture content

The following is the formula for calculating the wet basis moisture content of a material (Singh, 1984):

$$m = \frac{W_m}{W_m+W_d} \times 100\% \quad (3.3)$$

Explanation:

m = Wet basis moisture (%)

Wm = Weight of water in the material (g)

Wd = Weight of solid in the material (g)

3.3.4.2. Rate of Water Evaporation on a Material

The following is the formula for calculating the rate of water evaporation on a material (Singh, 1984):

$$DR = \frac{w_t - w_{t+1}}{w_a} \times \frac{1}{t_2 - t_1} \quad (3.4)$$

Explanation:

DR = Drying rate (kg/kg jam)

w_t = Initial weight of material (kg)

w_{t+1} = Weight of material at time (kg)

w_a = Weight of solid (kg)

t_1, t_2 = Change in time (jam)

3.3.4.3. Usage of Electrical Energy

Electrical energy is used to operate the control circuit, blower, and heating element (heater). The electrical energy requirement is calculated based on the duration of operation of the control circuit, blower, and heating element. The calculation of electrical energy used during performance testing with electrical energy (non-hybrid) and during hybrid energy is as follows:

$$Q_n = P_1 \text{ x } t_1 + P_2 \text{ x } t_2 + \ldots + P_n \text{ x } t_n \quad (3.5)$$

$$Q_h = P_1 \text{ x } t_1 + P_2 \text{ x } t_2 + \ldots + P_n \text{ x } t_n \quad (3.6)$$

Explanation:

Q_n = total non-hybrid electricity usage (kWh).

Q_h = total hybrid electricity usage(kWh).

P_1, P_2, P_n = power used (kW).

t_1, t_2, t_n = time the device is turned on (jam).

Calculating the energy savings of a dryer:

$$Q_p = \frac{Q_n - Q_h}{Q_n} \text{ x } 100\% \quad (3.7)$$

Q_p = Energy savings (%)

Q_n = Electricity used during performance testing with electricity (kWh).

Q_h = Electricity used during performance testing with hybrid electricity and solar energy (kWh).

4. RESULTS AND DISCUSSION

4.1. Gain Test

In this study, a gain test was conducted to see if the power in the dryer could exceed the setpoint temperature to be applied. The results of the gain test are as follows:

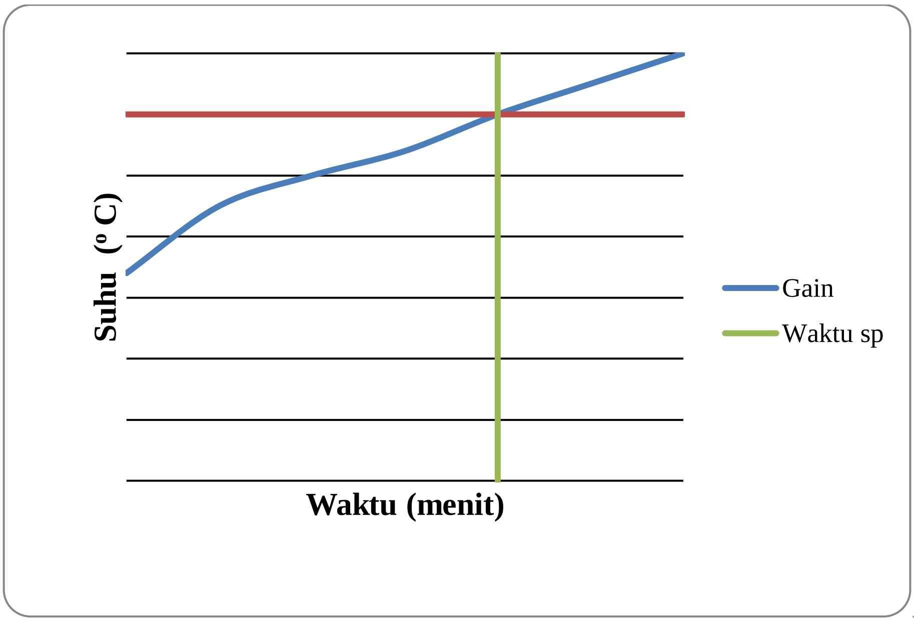

Figure 4.1. Gain Test

In Figure 4.1. shows that the temperature of the dryer can pass the setting point temperature to be applied. This shows that the power available in the dryer is large enough and can be used for the application of the control system. The power in the dryer is quite large, so a control system is needed so that the performance of the dryer matches the expected criteria. Based on the measurement of the heating power (heater) used by the dryer is 1,480 Watt. The rate of temperature increase of the dryer is 3.25oC/minute and the time required to reach the setpoint temperature (60oC) is 8 minutes.

4.2. Control Program

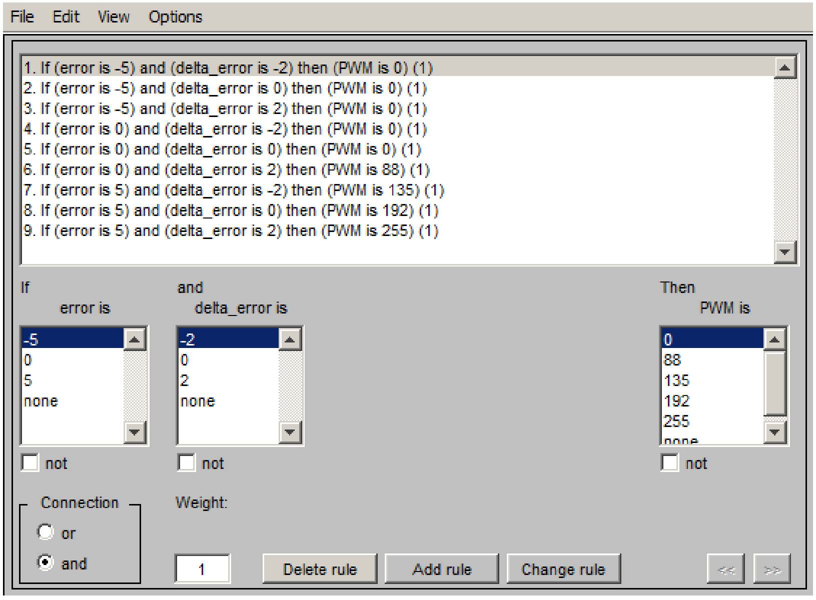

Figure 4.2. Control rules used

The Sugeno inference fuzzy logic control program that is applied using the input to the control system is the error value and delta error of the setpoint reading results with the drying room temperature while the output is the PWM (pulse width modulation) control signal. The error value range is (-5) to (+5), the delta error value range is (-2) to (+2) and the PWM value range is 0-255. The input membership function used in this study is a triangle with a number of 3. While the output is a singleton with a number of 5.

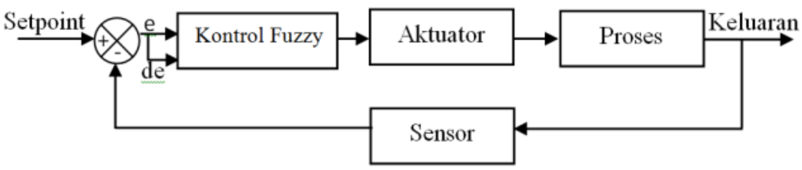

Figure 4.3. Block diagram of fuzzy logic control system

The control algorithm is when the sensor reads the temperature value in the drying room, it will be entered into the microcontroller and compared with the setpoint value. The difference between the sensor reading value and the setpoint is called error, while the error difference is called delta error. A negative error value indicates that the setpoint value has been passed, a positive error value indicates that the setpoint value has not been reached. While the negative delta error value indicates that the temperature is rising, and the positive delta error temperature is falling. The results of the error and delta error readings are entered into the control rules so that it will produce a control signal in the form of PWM which will control the actuator. The actuator will control the power supplied to the heater.

4.3. Functional Test

The functional test is to determine whether the air heating power is large enough to dry the material and to determine whether the control program can work as expected. In this study, functional tests were carried out without using materials with a setpoint temperature of 60oC to show the response of the control system. The temperature measurement results of the dryer are as shown in the following graph:

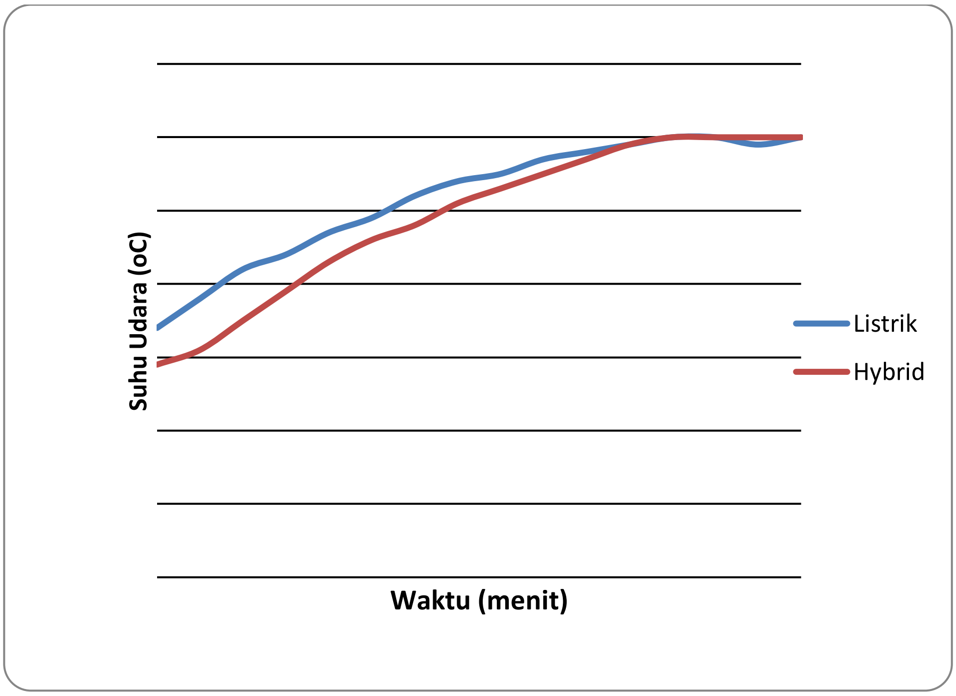

Figure 4.4. Dynamic response of the control on the dryer.

Figure 4.4 shows the dynamic response of the control on the dryer when using electrical energy (non-hybrid) and hybrid energy. The initial temperature of the drying chamber when using hybrid energy is smaller (29oC) than when using electrical energy (34oC), the time required to reach the setpoint (settling time) is the same at 12 minutes. The drying room temperature does not overshoot. According to Ogata (2002), the tolerance limit for overshoot values in closed-loop systems is 2-5% of the range of values used. This shows that the fuzzy control rules match the expected target of controlling the air temperature of the dryer.

4.4. Performance Test

Performance tests were carried out using wet sago starch material to see the moisture content of the material produced and the use of energy in the dryer with 2 conditions, namely:

4.4.1. Using electrical energy

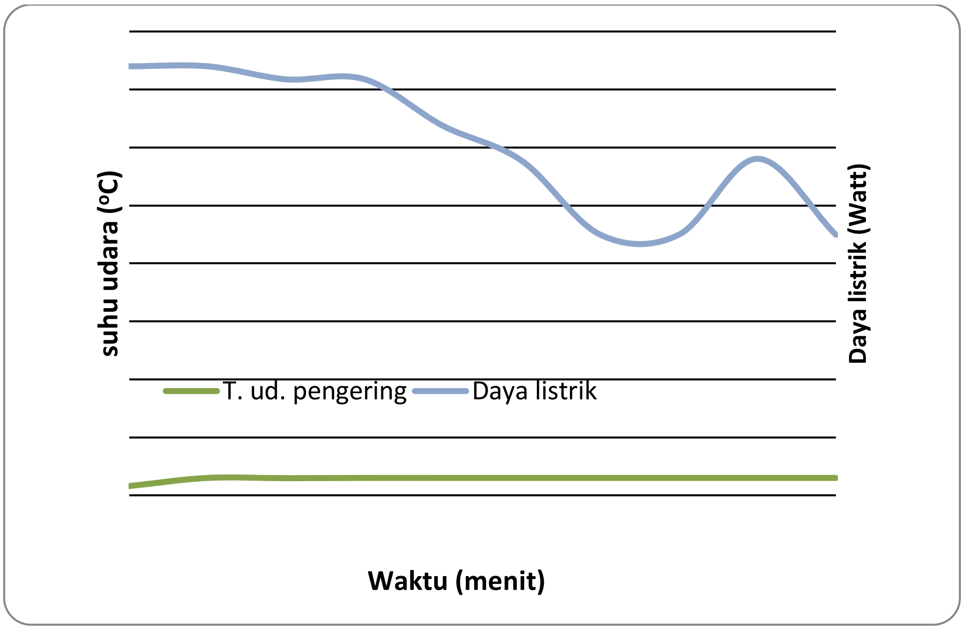

Figure 4.5. Air temperature and electrical power change during the sago drying process when using electrical energy.

Figure 4.5 shows the air temperature of the dryer and the electrical power during the 4.5-hour drying process. The control system works well with no overshoot and the drying room temperature stabilizes when it reaches the setpoint and the electric power gradually decreases. In the drying process using electrical energy using sago material with an initial moisture content of 44.65%bb with a final moisture content of 12.73%bb, the moisture content meets the SNI: 3729-2008 standard which is a maximum of 13%. The electrical energy used during the drying process amounted to 5.32 kWh.

4.4.2. Using hybrid energy

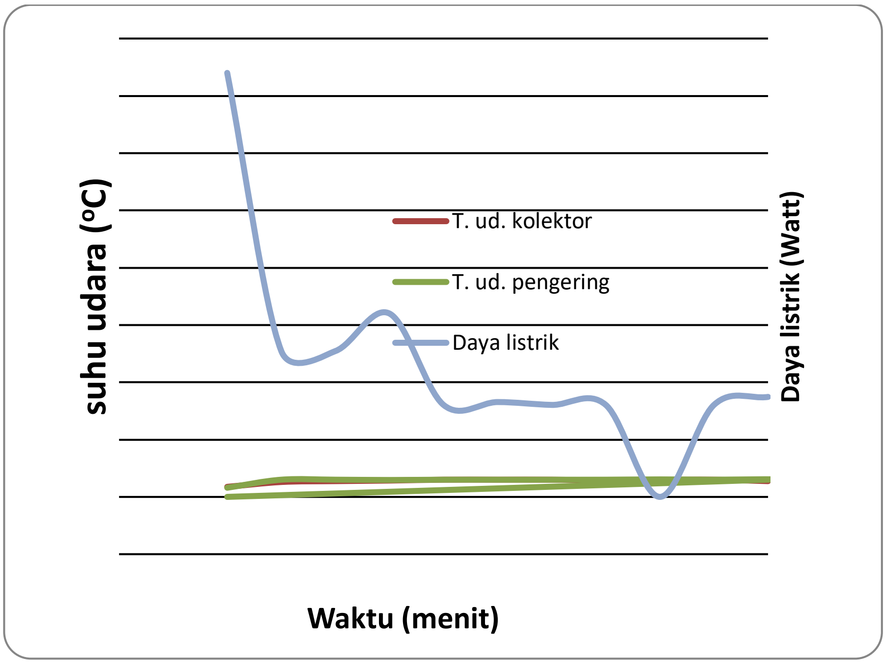

Figure 4.6. Air temperature and electrical power changes during the sago drying process when using hybrid energy.

Figure 4.6 shows the air temperature of the dryer and the change in electrical power when using hybrid energy (solar and electric) with a drying process duration of 5 hours. The control system works well with overshoot and small steady state error of 1oC, the drying room temperature is stable when reaching the setpoint and the time required to reach the setpoint is quite short. In the drying process using electrical energy using sago material with an initial moisture content of 46.48%bb with a final moisture content of 12.37%bb, the moisture content meets the SNI: 3729-2008 standard which is a maximum of 13%. The electrical energy used during the drying process amounted to 2.55 kWh.

4.5. Water Content

The purpose of this drying process is to obtain the moisture content of sago flour on each shelf and the average moisture content meets the quality requirements for moisture content according to SNI 01-3729-2008 which is 13% wet basis.

4.5.1. Moisture Content of Each Shelf

The observation results of the moisture content of each shelf for each drying process are as follows:

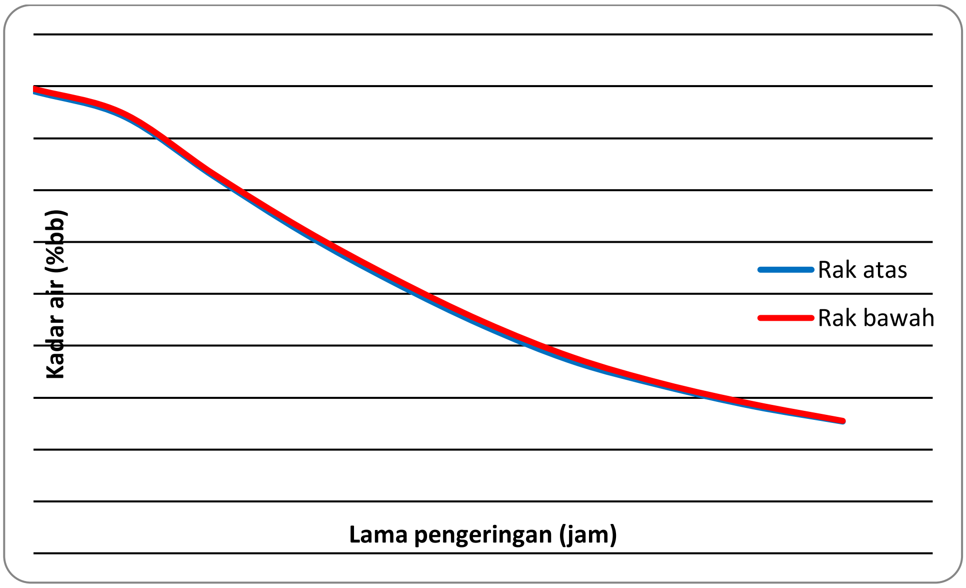

Figure 4.7. Moisture content of each shelf in electric drying.

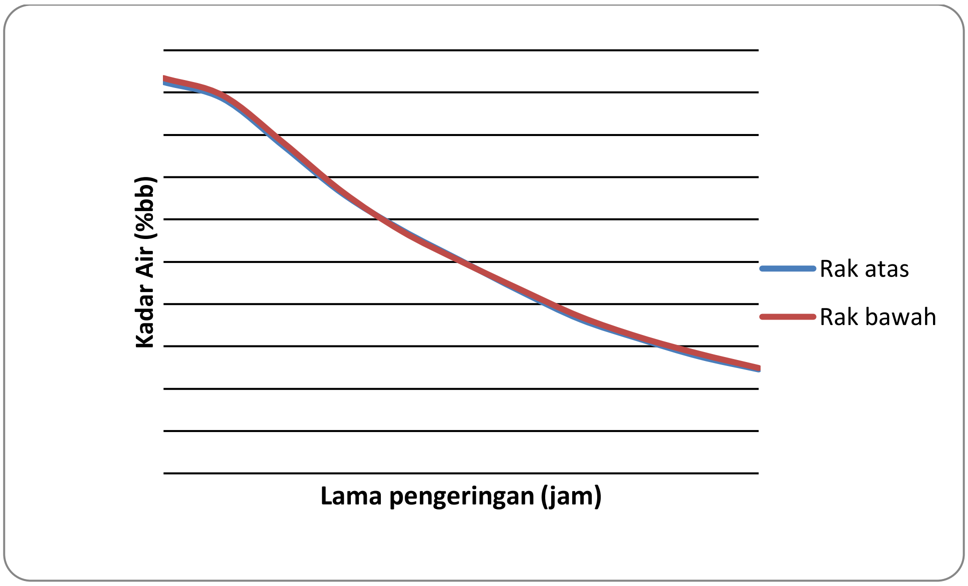

Figure 4.8. Moisture content of each shelf in solar and electric (hybrid) drying.

Based on the observations in Figure 4.7 and Figure 4.8, it shows that the decrease in moisture content in each is the same with the difference in moisture content of each shelf which is not much different and relatively small. This shows that the air entering the drying room is quite evenly distributed by using a blower to channel hot air into the drying room.

4.5.2. Average Moisture Content

The observation results of the average moisture content for each drying process are shown in Figure 4.9 as follows:

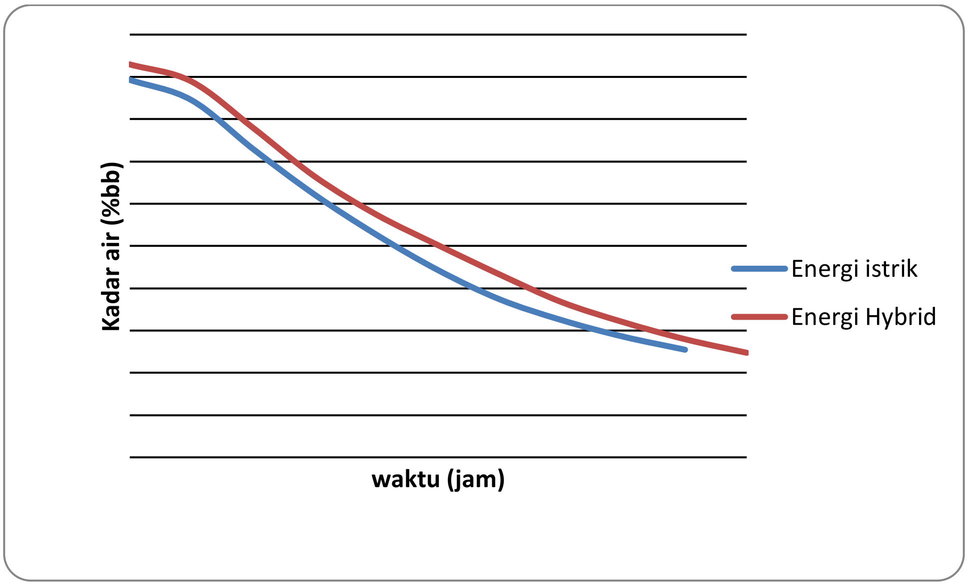

Figure 4.9. Average moisture content of each drying process.

Based on the observation of average moisture content in Figure 4.9. shows that both drying processes can achieve uniform moisture content which is between 12%-13% and meet the quality standards of sago flour moisture content SNI 3729-2008 which is a maximum of 13% wet basis, with a drying process time of 4.5 hours for electrical energy and 5 hours for hybrid energy. The drying time when using hybrid energy is relatively longer because the initial moisture content of sago is higher at 46.48%bb compared to the sago used in the drying process using electrical energy which is 44.65%bb.

4.6. Evaporation Rate

The observation results of the evaporation rate in the drying process can be seen in Figure 4.10 as follows:

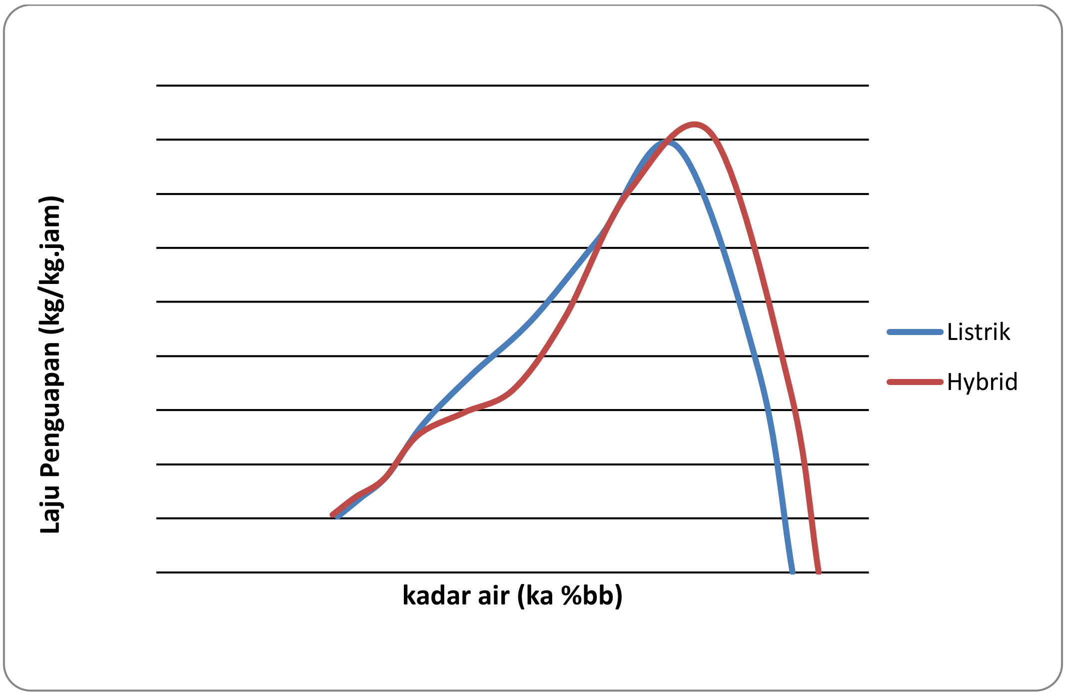

Figure 4.10. Average evaporation rate for each drying process.

Based on the observation of the water evaporation rate in Figure 4.10. shows that the beginning of the water evaporation process is lower because the temperature has not reached the setpoint, when the temperature reaches the setpoint the water evaporation rate increases. With time the evaporation rate decreases due to the smaller water content. In Figure 11 the highest water evaporation rate when using hybrid energy is 0.081 kg/kg.h and when using electrical energy is 0.079 kg/kg.h, this is because the moisture content of the material during the hybrid energy drying process is higher at 46.48% kabb compared to electrical energy which is 44.65% kabb. The average evaporation rate using electrical energy is 0.037 kg/kg.hour while using hybrid energy is 0.036 kg/kg. hour.

4.7. Electrical Energy Usage

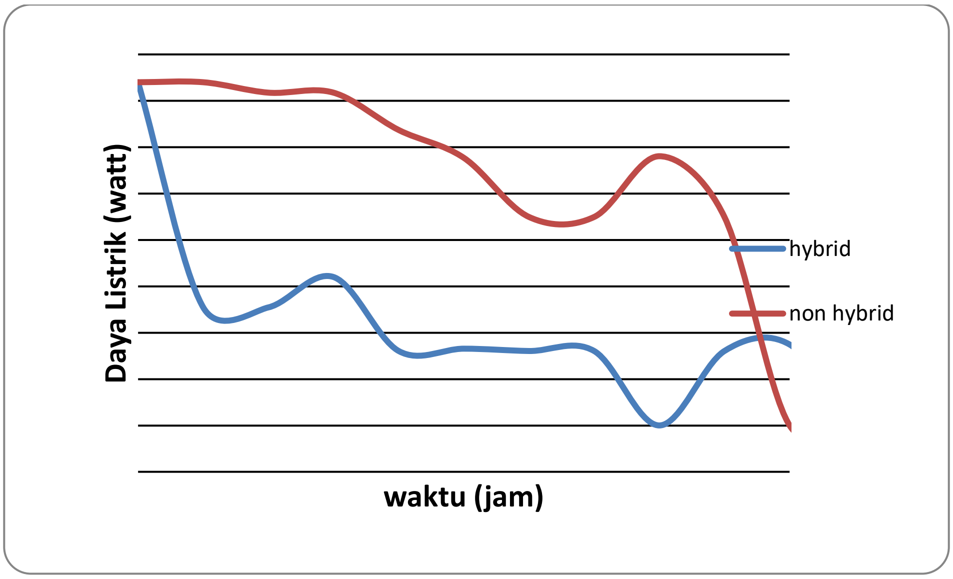

Figure 4.11. Electric power usage during drying

Figure 4.11 shows the use of electrical power when drying using electrical energy (non-hybrid) and using hybrid energy. The total electrical energy used when using electrical energy (non-hybrid) is 5.32kWh, while using hybrid energy is 2.55kWh. Electric energy savings when using hybrid energy amounted to 52.07%.

5. CONCLUSION

5. Conclusion

Based on the research that has been conducted, the following conclusions can be obtained:

1. A fuzzy logic control system has been designed and applied to a rack-type dryer with hybrid electric and solar energy and produces good performance, namely small overshoot (<5%), relatively short settling time, small and stable steady state error (<2%) and can save the use of electric power.
2. The hybrid electric and solar energy drying machine dries the sago well enough so that the moisture content of the sago produced is uniform between 12-13%bb and according to the target of SNI: 3729-2008 which is a maximum of 13% bb.
3. Electricity consumption in the hybrid drying process is more efficient than drying using electrical energy, which is 2.55kWh and 5.32kWh with a savings of 52.07%.

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ATTACHMENT

Attachment 1. Dryer Specifications

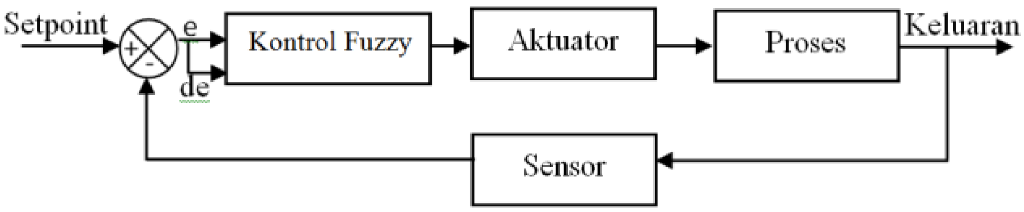
Specification of Dryer

Category	Description
Heater Power (Watt)	1480
Drying Chamber Dimensions (PxLxT)	57x57X68 (cm)
Number of Shelves	10
Materials	Aluminum, stainless steel
Blower	2.5 inch, 260 Watt
Drive Power	Power 220 V, 50Hz

Collector specifications

Category	Description
Dimensions (PxLxT) (cm)	184 x 93 x 12
Materials	Aluminum, acrylics

Attachment 2. Fuzzy Control Program Schematic



Attachment 3. Temperature observation during the Gain Test.

Time (minutes)	Dryer Air Temperature (ºC)
0	34
2	45
4	50
6	54
8	60
10	65
12	70

Attachment 4. Dynamic Response of Control Without Materials

time (minutes)	Dryer Air Temperature (ºC)	
	Hybrid	**Power**
0	29	34
1	31	38
2	35	42
3	39	44
4	43	47
5	46	49
6	48	52
7	51	54
8	53	55
9	55	57
10	57	58
11	59	59
12	60	60
13	60	60
14	60	59
15	60	60

Attachment 5. Control Dynamic Response With Materials

Time (Minutes)	Dryer Air Temperature (ºC)	
	Hybrid	Power
0	32	32
2	35	35
4	37	37
6	39	40
8	42	43
10	44	45
12	47	49
14	49	51
16	51	53
18	53	55
20	55	56
22	57	57
24	58	58
26	58	59
28	59	59
30	60	60
32	60	60
34	60	60
36	60	60
38	60	60
40	60	60

Attachment 6. The results of measuring the air temperature of the dryer during the drying process when the temperature of the steady state

Time (hour)	Dryer Air Temperature (ºC)	
	Power	*Hybrid*
0	32	32
	60	60
1	59	60
	60	59
2	60	60
	60	60
3	60	60
	60	60
4	60	61
	60	60
5		60

Attachment 7. Measurement results of moisture content of wet base (kabb) and dry base (kabk) of each shelf in the drying process using electrical energy

Time (hour)	Top shelf		Bottom shelf	
	Water content (%bb)	Water content (%bk)	Water content (%bb)	Water content (%bk)
0	44.53	80.28	44.76	81.04
	42.12	72.76	42.39	73.58
1	36.35	57.11	36.57	57.66
	30.88	44.67	31.23	45.41
2	26.12	35.36	26.52	36.08
	21.93	28.09	22.32	28.74
3	18.48	22.67	18.87	23.26
	16.12	19.22	16.34	19.53
4	14.17	16.51	14.37	16.79
	12.69	14.54	12.76	14.63

Attachment 8. Measurement results of moisture content of wet base (kabb) and dry base (kabk) of each shelf in the drying process using hybrid energy

Time (hour)	Top shelf		Bottom shelf	
	Water content (%bb)	Water content (%bk)	Water content (%bb)	Water content (%bk)
0	46.25	86.04	46.71	87.65
	44.27	79.44	44.65	80.65
1	38.77	63.32	39.16	64.36
	33.10	49.48	33.31	49.94
2	28.78	40.40	28.63	40.11
	25.12	33.55	25.04	33.41
3	21.50	27.39	21.71	27.74
	18.20	22.25	18.52	22.73
4	15.89	18.89	16.08	19.17
	13.82	16.03	14.13	16.45
5	12.28	14.00	12.45	14.22

Attachment 9. The results of measuring the average wet basis moisture content in each drying process with a material weight of 10 kg

Time (hour)	Water Content (%bb)	
	Power Energy	Hybrid Energy
0	44.65	46.48
	42.25	44.46
1	36.46	38.96
	31.05	33.20
2	26.32	28.70
	22.13	25.08
3	18.67	21.61
	16.23	18.36
4	14.27	15.99
	12.73	13.97
5		12.37

Attachment 10. The results of measuring the average drying rate in each drying process with a material weight of 10 kg

Time (hour)	Drying Rate (kg/kg hour)	
	Power Energy	Hybrid Energy
0	0	0
	0.037	0.034
1	0.079	0.081
	0.062	0.071
2	0.047	0.047
	0.037	0.034
3	0.027	0.030
	0.018	0.025
4	0.014	0.017
	0.010	0.014
5		0.011
Average	0.037	0.036

Attachment 11. Power energy savings

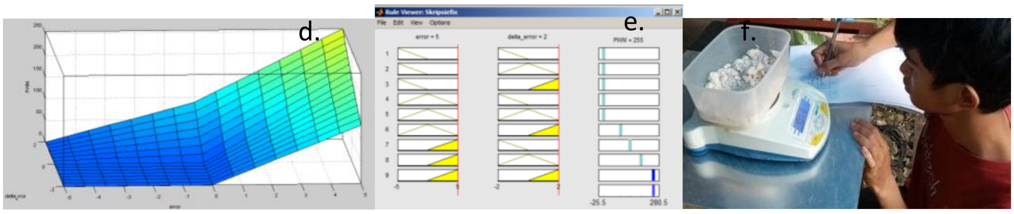
$$Q_p = \left(\frac{Q_n - Q_h}{Q_n}\right) x100\%$$

$$Q_p = \left(\frac{5.32\ kWh - 2.55\ kWh}{5.32\ kWh}\right) x100\%$$

$$Q_p = 52.07\ \%$$

Attachment 12. Research Documentation

(a). Drying equipment design; (b). Drying tool; (c). Control system hardware.



(d). Surface control system; (e). Rule view; (f). Weighing of wet sago.

(g).Material leveling on the shelf; (h). Inserting rack into tool; (i). Uploading the program.

(j). Uploading the program; (k). Sample weighing (l). Drying result.