

## Fuzzy Logic Implementation in Determining Sponge Cake Characteristics Based on Temperature and Baking Time

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### Abstract

Cake is a popular sweet food made primarily from wheat flour, sugar, eggs, and milk processed by baking. Sponge cake is one of the most popular types of cake. Sponge cake has a slightly rough texture and has large pores like sponge. Baking temperature and time have a crucial role in achieving optimal volume, texture, and density of the sponge cake. Overbaking and underbaking can negatively impact the moisture and softness. The purpose of this research is to determine the optimal temperature and baking time to produce a good sponge cake. The methods used in this research include a literature review and the implementation of fuzzy logic coupled with MATLAB application toolbox. The results of this research must be present a solution to optimize temperature control and baking time that can help produce consistent and high quality sponge cake products. However, the results are uncomprehensive.

**Keywords:** baking, fuzzy logic, sponge cake

### INTRODUCTION

*Cake* is a type of sweet food with the main ingredients in the form of wheat flour, sugar, eggs, and fat and the processing process involves the baking or steaming process to produce a distinctive texture (Adinda Gildaf and Gusnadi, 2023). *Cake* has many variants, one of which is *sponge cake*. *Sponge cake* can be defined as a type of *cake* with a thick dough, has a rather rough texture, is less elastic, tends to crumble easily when cut, and has large pores similar to foam, so this *cake* is often referred to as *foam cake* (Marzec *et al.*, 2021). *High-quality sponge cakes* generally have several characteristics, such as a large volume, a *crumb* texture with small and uniform pores, and a crust surface that is not too brownish, accompanied by a distinctive cake aroma (Ambarwati *et al.*, 2020).

The volume produced during baking is crucial in determining the final quality of *sponge cake*, as it affects the texture and density of the product (Hajrah *et al.*, 2019). Temperature and baking time are key factors in shaping the volume of *sponge cake* (Dizlek and Altan, 2021). Oven temperatures that are too high can cause *the cake* to burn with a less attractive surface. On the other hand, the temperature is too low resulting in *the cake* not rising properly and tends to be dense or slammed. Baking time also plays an important role, too short a time can make *the cake* not cooked evenly, so that the inside is still soft and unstable. On the other hand, if the baking time is too long, the *cake* can become dry and lose moisture, resulting in a less tender texture (Firdausa 2020).

The implementation of *fuzzy logic* in the sponge cake *making process* can provide a solution to optimize temperature control and baking time, resulting in consistent and high-quality products. *Fuzzy logic* is a logical concept that considers the degree of uncertainty or *fuzziness* between right and wrong. In this theory, a value can have elements of truth and error at the same time. The degree of truth or error is determined by the membership weight that the value has. *Fuzzy logic* has a membership range from 0 to 1, in contrast to digital logic which has only two values, namely 1 or 0. *Fuzzy logic* is used to translate quantities expressed in linguistic language (Nugraha, 2018).

Previous research has shown that fuzzy logic can be used to optimize temperature control processes in food production. Ullah *et al.*, (2018) stated that the application of fuzzy logic in bread *proofing* machines produces more stable temperature and humidity control compared to conventional control so that it provides more consistent results in dough development. Research by Syarif *et al.*, (2023) also shows that *fuzzy logic* allows for more adaptive and intuitive temperature control, and can adjust to the stages of the baking process, load variations, and environmental conditions, thereby improving product quality, process efficiency, and reducing the risk of product damage. Therefore, this research focuses on the application of a *fuzzy logic-based* control system to optimize the temperature and baking time in the manufacture of *sponge cake*, with the aim of producing consistently high-quality products.

## **METHODS**

The method used in writing this journal is a *Study Literature Review (SLR)* from several journals that are relevant to the topic taken and data analysis using a *fuzzy logic control system*. The SLR method is used to identify, review, evaluate, and interpret all available research on the topic area of an interesting phenomenon, with certain relevant research questions (Triandini *et al.*, 2019).

The *Literature Review (SLR) Study Method* which provides various information can help us in preparing this journal (Sari *et al.* 2023). Literature study can be called a method that has accurate relevance because it involves presenting information, collecting data, and selecting data with relevant information from various sources such as articles, scientific journals, and other publications. Apart from that, the use of a *fuzzy logic control system* with mamdani method, in this journal aims to determine the implementation of how to determine the characteristics of sponge cake based on temperature and baking time. These criteria are relative in nature, so a fuzzy Mamdani model can be used to obtain the right choice from something vague using a Matlab application logical system (Yanti *et al.*, 2022).

In the *fuzzy logic* calculation system, there is a determination of a *fuzzy* set for each *fuzzy* variable that will be used as "*input*" to the *fuzzy* inference system, where the input in this journal is the temperature and baking time of the sponge cake. The temperature variable consists of three parameters, namely low, medium and high which will be calculated to get the midpoint by forming a triangle in the Matlab application. To determine the effect of temperature and time on the characteristics of sponge cake.

### **Membership Functions**

Membership function or membership type is a curve that maps input data points into membership values with an interval range between 0 and 1 (Gozali, 2020). This membership function is used to describe human logic parameters (Susanto *et al.*, 2019). Fuzzy set description rules must be followed to be able to describe fuzzy membership functions in several different ways (Harliana and Rahim, 2017). Membership functions have two types, namely: Triangular Membership Function and Trapezoidal Membership Function (Abdi, 2018).

#### **Triangular Membership Function**

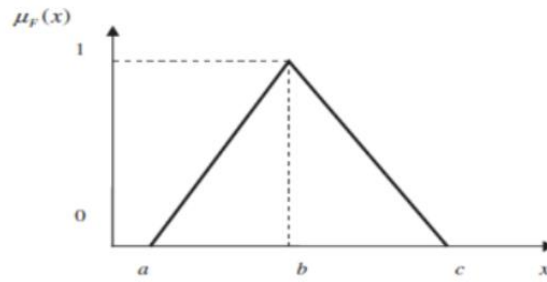


Figure 1. Triangular Membership Function

The graph of a triangular membership function is basically a combination of two straight lines (linear) (Dharma et al., 2015). This graph functions to determine the highest degree of membership (Siskandar et al., 2023). The membership set for the graph of a triangular membership function is written as  $\mu_F(a, b, c)$ .

### Trapezoidal Membership Function

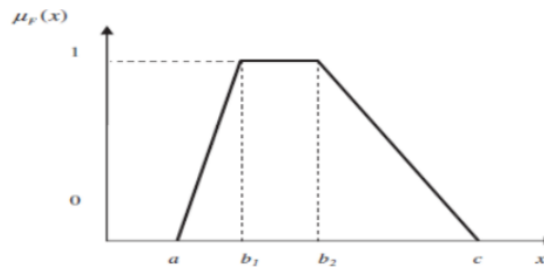


Figure 2. Trapezoidal Membership Function

The trapezoid curve is basically similar to a triangle shape, but there are several points on this curve that have a membership value of 1 (Yulia and Mardiah, 2018). Membership set for the graph of the Trapezoidal Membership Function  $\mu_F(a, b_1, b_2, c)$ .

## RESULTS AND DISCUSSION

The literature review conducted aims to base decisions on the optimization of temperature and time in the sponge cake baking process, considering the volume of the sponge cake in the final product. Contributing factors to this decision include the batter temperatures used (Dizlek and Altan, 2021). Additionally, the percentage of baking powder in the sponge cake formula also affects the volume of the sponge cake in the final product.

To determine the optimal temperature and time for producing a high-quality product, it is essential to ensure the consistent application of temperature and time by integrating the obtained data into fuzzy logic. This approach enhances the validity of optimizing temperature and time in relation to the volume of the final product.

### Literature Study Data

The following is a table of data obtained from literature studies.

Table 1. Literature Study Data

Variable	Fuzzy Parameter	Range			
		Set	a	b	c
Temperature (°C)	Low	160-190	160	175	190
	Medium	180-210	180	195	210
	High	200-230	200	215	230
Baking Time (minutes)	Short	20-28	20	24	28
	Medium	26-34	26	30	34
	Long	32-40	32	36	40
Volume	Bad	1435-1555	1435	1495	1555
	Medium	1525-1645	1525	1580	1645
	Good	1605-1725	1605	1665	1725

Source: (Dizlek and Altan, 2021)

### Case Study

The case study used has a high temperature criterion with a value of (215) and a short time criterion with a value of (25), so that an assessment will be produced. After getting the case study, the next step is to complete the Fuzzy Inference System (FIS) stages as follows.

### Determining Input and Output Variables

Fuzzy variables can be interpreted as variables that will be discussed in a fuzzy system (Rindengan and Yohanes, 2019). Basically, fuzzy variables help in decision making or assessment in systems that do not have definite value limits, but rather are represented by a range or fuzzy set (Haque and Sriani, 2023). In this case, there are two fuzzy variables as input, namely time and temperature of baking sponge cake and there is one fuzzy variable as output, namely the volume of sponge cake.

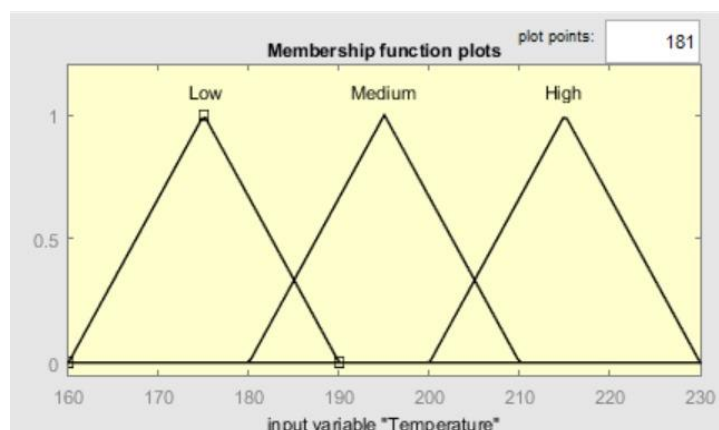


Figure 3. Input Temperature

This figure illustrates the temperature input variable within a range of 160-230, categorized into three parameters: Low, Medium, and High.

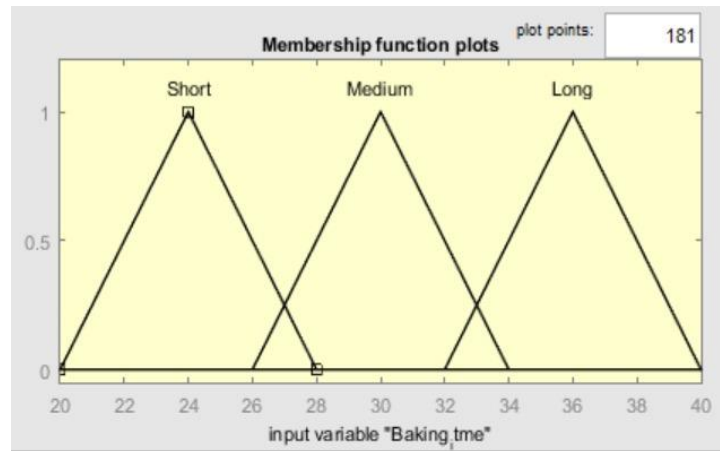


Figure 4. Input Baking Time

This figure illustrates the time input variable within a range of 20-40, categorized into three parameters: Short, Medium, and Long.

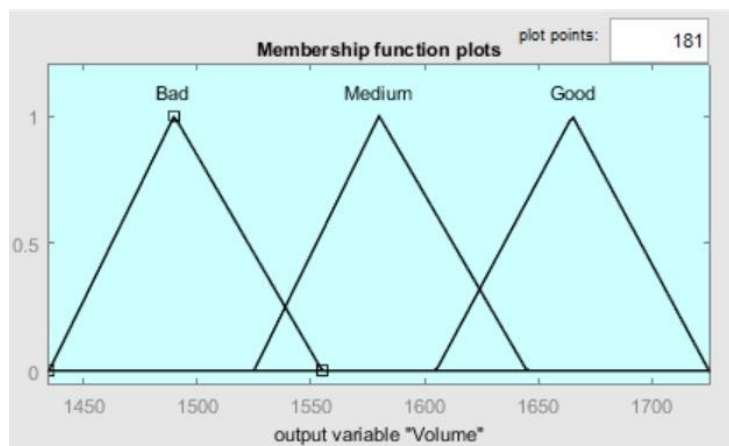


Figure 5. Output Volume

This figure depicts the output volume variable within a range of 1450 to 1700, categorized into three parameters: Bad, Medium, and Good.

### Building Fuzzy Membership Set

The degree of membership of the fuzzy set is used to find out how much the input value goes into the fuzzy set. Each membership function has certain parameters that determine the shape of the curve and the value of the degree of membership given by each input value (Antoni and Findawati, 2024). In obtaining input and output data, an accurate value is required and can be in harmony with the data that is in the predetermined range (Arief *et al.*, 2024).

### Temperature Input Membership Set

The first input to the temperature variable contains three fuzzy parameters, namely low, medium and high. These three parameters are processed to get the midpoint by forming a triangle in the MATLAB application section, the low parameter has a midpoint of 175, the medium parameter has a midpoint of 195, and the high parameter has a midpoint of 215.

$$\mu_{Low} \left\{ \begin{array}{ll} x < 160 & 0 \\ 160 \leq x < 175 & \frac{x-a}{b-a} \\ x = 175 & 1 \\ 175 < x \leq 190 & \frac{c-x}{c-b} \\ x > 190 & 0 \end{array} \right.$$

The low parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (160-174), second in the peak area with numbers (175), and finally in the right area with numbers (176-190).

$$\mu_{Medium} \left\{ \begin{array}{ll} x < 180 & 0 \\ 180 \leq x < 195 & \frac{x-a}{b-a} \\ x = 195 & 1 \\ 195 < x \leq 210 & \frac{c-x}{c-b} \\ x > 210 & 0 \end{array} \right.$$

The medium parameters are divided into three parts which can be used as a formula, namely first in the left area with numbers (180-194), second in the peak area with numbers (195), and finally in the right area with numbers (196-210).

$$\mu_{High} \left\{ \begin{array}{ll} x < 200 & 0 \\ 200 \leq x < 215 & \frac{x-a}{b-a} \\ x = 215 & 1 \\ 215 < x \leq 230 & \frac{c-x}{c-b} \\ x > 230 & 0 \end{array} \right.$$

The high parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (200-214), second in the peak area with numbers (215), and finally in the right area with numbers (216-230).

### Baking Time Input Membership Set

The second input is a baking time variable with three fuzzy parameters, namely short, medium and long. These three parameters are processed to get the midpoint by forming a triangle in the MATLAB application section, the short parameter has a midpoint of 24, the medium parameter has a midpoint of 30, and the long parameter has a midpoint of 36.

$$\mu_{Short} \left\{ \begin{array}{ll} x < 20 & 0 \\ 20 \leq x < 24 & \frac{x-a}{b-a} \\ x = 24 & 1 \\ 24 < x \leq 28 & \frac{c-x}{c-b} \\ x > 28 & 0 \end{array} \right.$$

The short parameter is divided into three parts which can be used as a formula, namely the first in the left area with numbers (20-23), second in the peak area with numbers (24), and finally in the right area with numbers (25-28).

$$\mu_{Medium} \left\{ \begin{array}{ll} x < 26 & 0 \\ 26 \leq x < 30 & \frac{x-a}{b-a} \\ x = 30 & 1 \\ 30 < x \leq 34 & \frac{c-x}{c-b} \\ x > 34 & 0 \end{array} \right.$$

The medium parameters are divided into three parts which can be used as a formula, namely first in the left area with numbers (26-29), second in the peak area with numbers (30), and finally in the right area with numbers (31-34).

$$\mu_{Long} \left\{ \begin{array}{ll} x < 32 & 0 \\ 32 \leq x < 36 & \frac{x-a}{b-a} \\ x = 36 & 1 \\ 36 < x \leq 40 & \frac{c-x}{c-b} \\ x > 40 & 0 \end{array} \right.$$

The long parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (32-35), second in the peak area with numbers (36), and finally in the right area with numbers (37-40).

### Volume Output Membership Set

The membership set volume output is a volume variable with three fuzzy parameters, namely bad, medium and good. These three parameters are processed to get the midpoint by forming a triangle in the MATLAB application section, the bad parameter has a midpoint of 1495, the medium parameter has a midpoint of 1585, and the good parameter has a midpoint of 1665.

$$\mu_{Bad} \left\{ \begin{array}{ll} x < 1435 & 0 \\ 1435 \leq x < 1495 & \frac{x-a}{b-a} \\ x = 1495 & 1 \\ 1495 < x \leq 1555 & \frac{c-x}{c-b} \\ x > 1555 & 0 \end{array} \right.$$

The bad parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (1435-1494), second in the peak area with numbers (1495), and finally in the right area with numbers (1496-1555).

$$\mu_{Medium} \left\{ \begin{array}{ll} x < 1525 & 0 \\ 1525 \leq x < 1580 & \frac{x-a}{b-a} \\ x = 1580 & 1 \\ 1580 < x \leq 1645 & \frac{c-x}{c-b} \\ x > 1645 & 0 \end{array} \right.$$

The medium parameters are divided into three parts that can be used as a formula, namely the first area on the left with the numbers (1525-1579), the second area at the top with the numbers (1580), and the last area on the right with the numbers (1580).

$$\mu_{\text{Good}} \begin{cases} x < 1605 & 0 \\ 1605 \leq x < 1665 & \frac{x-a}{b-a} \\ x = 1665 & 1 \\ 1665 < x \leq 1725 & \frac{c-x}{c-b} \\ x > 1725 & 0 \end{cases}$$

The good parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (1605-1664), second in the peak area with numbers (1665), and finally in the right area with numbers (1666-1725).

### Determining the Sponge Cake Volume

In determining the quality of sponge cake volume, focus on the case study where the input is a short baking time of 25 minutes and a high baking temperature of 215°C.

### Baking Time Input ( Short : 25)

It is known that the variable that has a great influence on the X value is the short burning time, namely 25.

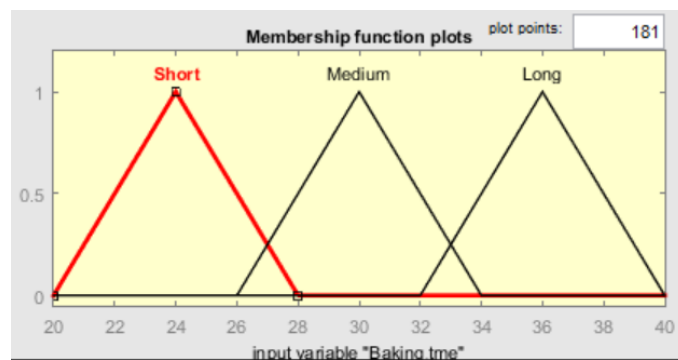


Figure 6. Short Baking Time 25 Input

Since the X value is included in the short parameter, then to calculate it use the height parameter formula. After that, draw a straight line up and on the right side.

$$\mu_{\text{Short}} \begin{cases} x < 20 & 0 \\ 20 \leq x < 24 & \frac{x-a}{b-a} \\ x = 24 & 1 \\ 24 < x \leq 28 & \frac{c-x}{c-b} \\ x > 28 & 0 \end{cases}$$

Because it concerns the right side, the formula is used to calculate the right side. The calculation result is 0.75 for the time variable

X = 25 use the right side formula, namely

$$\frac{c-x}{c-b} = \frac{28-25}{28-24} = \frac{3}{4} = 0.75$$

## Baking Temperature input (High : 215)

It is known that the variable that has a great influence on the X value is the combustion temperature at a high temperature, namely 215°C, then below is chart

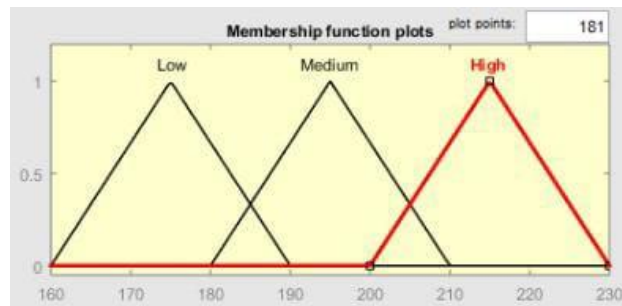


Figure 7. Input High Baking Temperature

Since the X value is included in the high parameter, then to calculate it use the short parameter formula. After that, draw a straight line up and on the left side.

$$\mu_{High} \begin{cases} x < 200 & 0 \\ 200 \leq x < 215 & \frac{x-a}{b-a} \\ x = 215 & 1 \\ 215 < x \leq 230 & \frac{c-x}{c-b} \\ x > 230 & 0 \end{cases}$$

Because it concerns the left side, the formula is used to calculate the left side. So it is known that  $x = 215$  and the calculation result is 1 for the temperature variable

$$= \frac{c-x}{c-b} = \frac{230-215}{230-215} = 1$$

## Determining Fuzzy Operators

The next step is to determine the fuzzy operator. At this stage it is used to determine the quality of Sponge Cake. The rules follow the IF-THEN format.

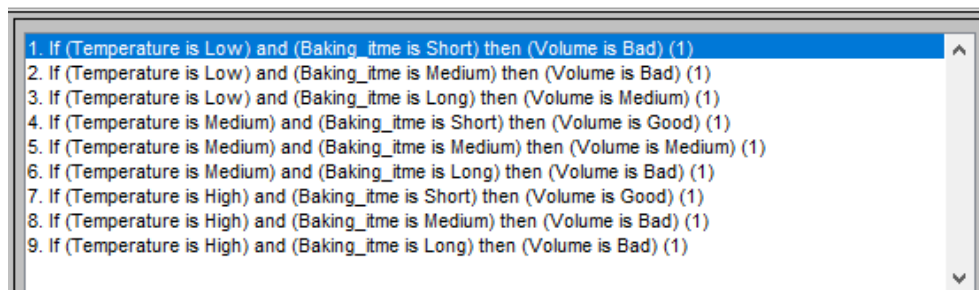


Figure 8. Fuzzy Rules Base

A fuzzy set defined by a membership function is termed a consequent. During implication, the consequent is modified based on the antecedent, resulting in a new fuzzy set. The Min operator is used to determine the  $\alpha$ -predicate for each rule (Putri and Saputro, 2021).

This fuzzy rule base is using “AND” rules, that the two inputs must be interconnected. Because to get the “good” output, the input needs to be “high” temperature with “short” baking time. So that the rules obtained are the number 7 rules. If the implication function uses the “AND” operator, then the minimum role is taken. On the other hand, if the implication function uses the “OR” operator, then the maximum role is taken (Yunan and Ali, 2020). Because using “AND” rules, the next step is determining the minimum value of two membership degrees using 1 and 0,75. Fuzzification of input variables is performed using membership functions, followed by the evaluation of fuzzy rules (firing strength) using the AND operator (min or product) in the IF section. Subsequently, the consequent of the fuzzy rules is established through linear equations in the THEN section, and finally, defuzzification is carried out using the weighted average method to obtain the final crisp output value (Sitinjak *et al.*, 2024)

$$\alpha = \min(1 : 0,75)$$

$$\alpha = 0,75$$

### Determining the Implication Function

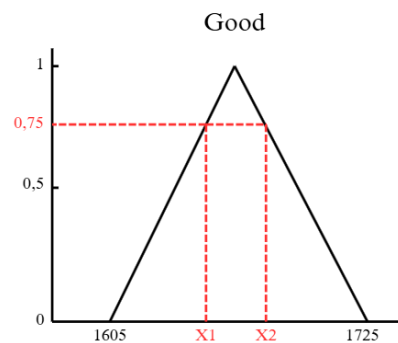


Figure 9. Implication Value

To get the value of X1 dan X2, is using the same formula as the output data using left side and right side rules.

Left side equation :

$$\alpha = \frac{X1-a}{b-a}$$

$$0,75 = \frac{X1-1605}{1665-1605}$$

$$45 = X1 - 1605$$

$$X1 = 1650$$

Right side equation :

$$\alpha = \frac{c-X2}{c-b}$$

$$0,75 = \frac{1725-X2}{1725-1665}$$

$$45 = 1725 - X2$$

$$X2 = 1680$$

From the above calculations, the results of the X1 implication value are 1650 and X2 1680.

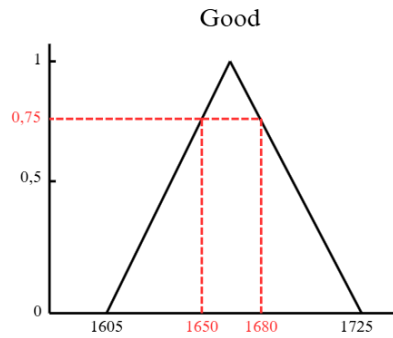


Figure 10. Implication of X1 and X2

Then the composition of data values into a new formula which becomes the formula for the last stage later, this formula is divided into three parts between (a, x1) (x1, x2) and (x2, c) as below.

$$f(x, a, b, c) = \begin{cases} x < 1605 & 0 \\ 1605 \leq x < 1650 & \frac{x-1605}{1665-1605} \\ 1650 \leq x \leq 1680 & 0,75 \\ 1680 < x \leq 1725 & \frac{1725-x}{1725-1665} \\ x > 1725 & 0 \end{cases}$$

### Defuzzification

Defuzzification is the process of converting fuzzy output into crisp values according to the specified membership functions (Nugroho *et al.*, 2019). The crisp values obtained from defuzzification are then compared with actual data (Mada *et al.*, 2017).

### Calculating the Area

After defuzzification, the subsequent step involves calculating the area in the case study. In this stage, the output variable is the main focus, representing the value that has been predetermined. To compute this area, it is necessary to use the appropriate formulas for planar geometric shapes based on the results of the implication function (as illustrated in the implication function diagram), as follows:

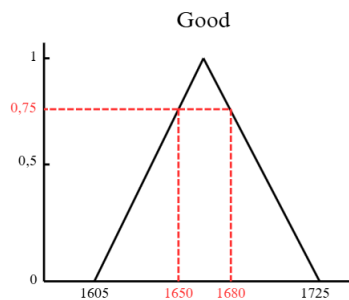


Figure 11. Implication of X1 and X2

$$A1 = \frac{(1650 - 1605) \times 0,75}{2} = 16,875$$

$$A2 = (1680 - 1650) \times 0,75 = 22,5$$

$$A3 = \frac{(1725 - 1680) \times 0,75}{2} = 16,875$$

### Moment Calculation Formula

The following are advanced formulas for the implications of functions that will formulate the moment calculation:

$$\begin{array}{rcl}
x < 1605 & 0 & = 0 \\
1605 \leq x < 1650 & \frac{x-1605}{60} & = 0,017x - 26,75 \\
1650 \leq x \leq 1680 & 0,75 & \\
1680 < x \leq 1725 & \frac{1725-x}{60} & = 28,75 - 0,017x \\
x > 1725 & 0 & = 0
\end{array}$$

Based on the calculations above, it is evident that if the value of x is greater than 1725, this value is interpreted as 0.

### Moment Calculation 1

This first moment uses the x-value 1605 as the lower limit and 1650 as the upper limit. Calculate it using the integral formula of the upper limit minus the lower limit.

$$M1 \int_{1605}^{1650} (0,017z - 27,73) z dz = 67324.5$$

### Moment Calculation 2

The second moment calculation also uses an integral calculation. The lower limit is 1650 with an upper limit of 1680.

$$M2 \int_{1650}^{1680} (0,75z) z dz = 37462.5$$

### Moment Calculation 3

This last moment calculation uses a lower limit value of 1680 and an upper limit value of 1725. The calculation is as below.

$$M3 \int_{1680}^{1725} (28,75 - 0,017z) z dz = -14877$$

### Defuzzification (II)

The final step in the calculation is defuzzification, which serves as validation that the previous calculations are in line with the results.

$$Z^* = \frac{\sum M}{\sum A} = \frac{67.324,5 + 37.462,5 - 14.877}{16,87 + 22,5 + 16,87} = 1598$$

The manual calculation result obtained is 1598, this outcome confirms inaccurate result of the preceding calculations cause gap between Matlab calculation and reality about 65.

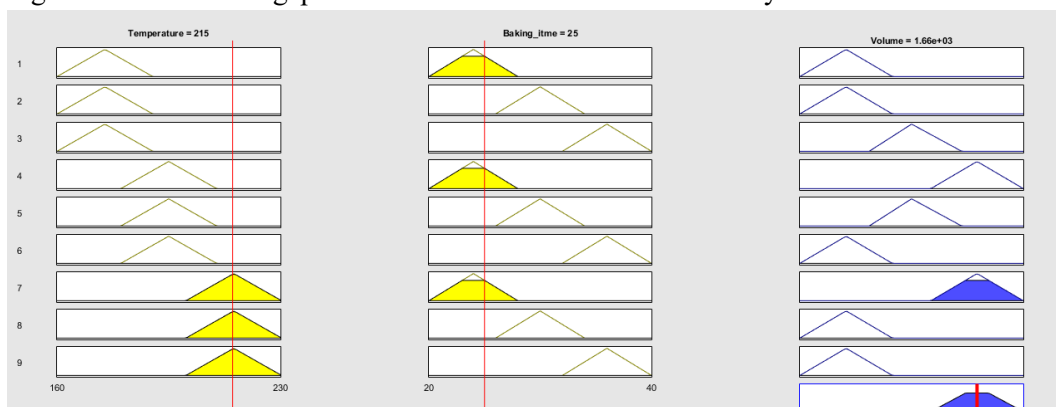


Figure 12. Rules Calculation

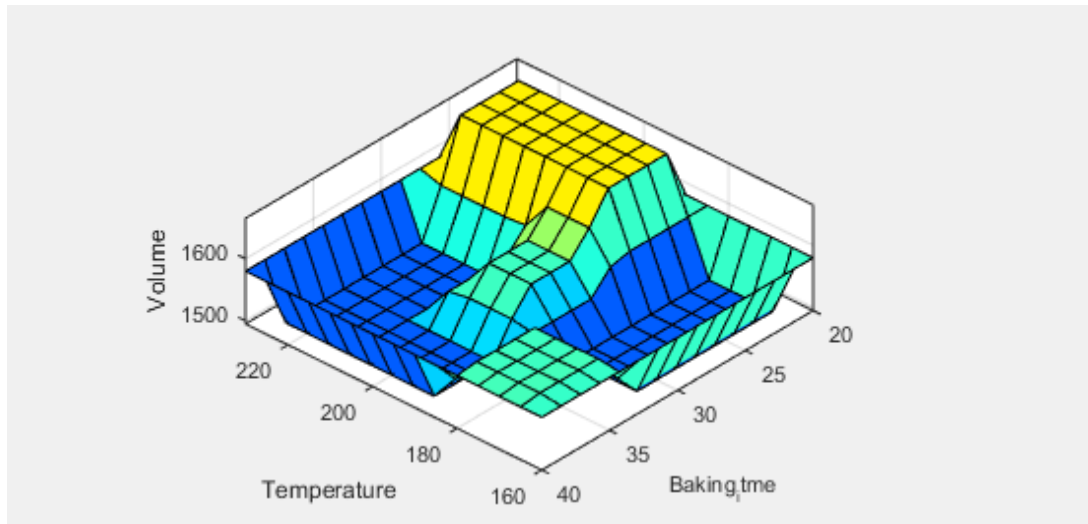


Figure 13. Sponge Cake Surface

## CONCLUSION

The conclusion of the application of fuzzy logic is supported by matlab in determining sponge cake characteristics based on temperature and baking time using the Study Literature Review (SLR) and Mamdani method. This study involved three variables, namely temperature with low, medium, and high parameters, time with short, medium, and long parameters, and finally volume with bad, medium, and high parameters. The fuzzy logic used is triangular and trapezoidal membership functions to determine the degree of membership which call as mamdani method. A case study is presented, showing the application of fuzzy inference system (FIS) to calculate the rating for high baking temperature (215) and short baking time (25). FIS involves determining input and output variables, constructing fuzzy membership sets, determining degrees of membership, fuzzy operators, and implication functions. Defuzzification is then applied to obtain the final values. This study provides uncomprehensive result from determine the roasting time and temperature to produce the sponge cake characteristics depending on its volume.

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