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Optimazion Analysis of Temperature and Fermentation Controlled Chamber (TFCC) with Hybrid System to Control Fermentation on Tape

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A B S T R A C T

The aim of this research is to determine analysis for optimizing tape fermentation using a Temperature and Fermentation Controlled Chamber (TFCC) with a Hybrid System. The resulting numerical model was analyzed using a non-linear differential method using Runge-Kutta. The thing that was analyzed was the change in the rate of yeast concentration, the rate of change in the concentration of ethanol and glucose resulting from the fermentation process. TFCC with Hybrid System Technology is equipped with an automated system accompanied by sensors that detect food quality and can be directly observed through the LCD screen integrated in the device. The research method used is experimental research by designing a tool that can be used to produce/cook fermented foods while monitoring pH, alcohol, glucose levels and temperature levels which are integrated in a set of tools called the TFCC with Hybrid Systems Technology . From the numerical explanation, it can be seen that when t is small, the rate of yeast development in the fermentation process will be small, the number of yeast cells is still small. As a result, the growth rate will be slow. This can be seen from the graph of the increase in X(t) and P(t) as well as the graph of S(t) which is still slow. The greater the time t, the rate of yeast consumption is also greater because the number of yeast cells is also increasing. As a result, the growth rate of ethanol and sugar is also large. This can be seen from the graph of an increase in X(t) and P(t) as well as a graph of a faster decline in S(t). When the maximum consumption rate is reached, then the values of X(t), S(t) and P(t) are constant. The amount of concentration in the resulting ethanol is close to the initial concentration of sugar produced.

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1. INTRODUCTION

Classic problems that still occur in society require a touch of technology as a solution to minimize the negative impact of fermented food processing. Among the forms of touch of technology that have been seen being applied in

society, such as ripeness detection devices and controls on tape as one of the fermented food objects (Djunaidi, 2019). These findings can only detect and control ripeness, without knowing the content of probiotic elements, alcohol content and the degree of acidity arising from the food's ripening process. Another finding is an alcohol level detector for types of alcoholic beverages using an Atmega328-based MQ-3 sensor (Adayana, 2015). The discovery only focused on the analysis of the alcohol content of the drink, but ignored the fermentation process. From some of the findings that are still limited, new innovations are needed that are more flexible and can integrate the requirements needed to produce quality fermented food products. One tool that can guarantee the growth of microbes in fermentation and the products from these microbes is a bioreactor. However, its use exists in the even distribution of culture medium and there is no integrated control and monitoring that can support the fermented food production process (Rofi'i, 2022). Moreover, the traditional scale fermented food processing system neglects the control and monitoring of production results, starting from the degree of acidity, alcohol content and ripeness. integrated fermented food through a medium that functions as a cooking furnace and controls food quality monitoring, starting from the degree of acidity, glucose content to alcohol content which is controlled by an automation module system and sensors through the Temperature And Fermentation Controlled Chamber (TFCC) Design.

2. LITERATURE REVIEW

Design of *Temperature And Fermentation Controlled Chamber* (*TFCC)*

The *Temperature And Fermentation Controlled Chamber* (*TFCC) with Hybrid System* Technology is equipped with an automated system accompanied by sensors that detect food quality and can be directly observed through the LCD screen integrated on the device. Sensors used include MQ-3 as a sensor for detecting alcohol levels, type K *thermocouple* to detect temperature levels, pH meter to measure acidity levels of fermented food and equipped with a tft LCD to display notifications of results of measurements. The design of the *Temperature And Fermentation Controlled Chamber* (*TFCC) with Hybrid System* Technology can be presented in the following figure.

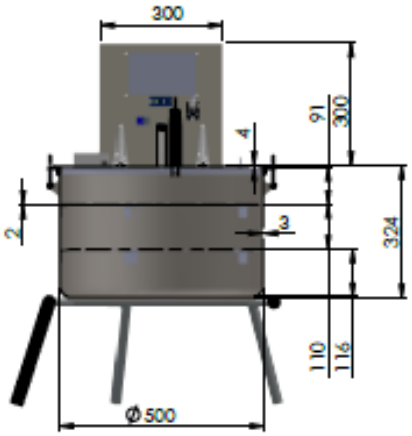


Figure 1. Design of TFCC

In this tool, which is used to produce/cook raw materials in the form of cassava as the basic ingredient for making fermented food products. After the fermented food has cooled with the help *of air flow* then yeast is given at a certain rate. Then it is stored back in the production media and activated by the integrated designed pH, alcohol and glucose monitoring components.

Runge-Kutta method

The Runge-Kutta method is part of a one-step numerical method with the solution of the initial conditions problem $x' = f(t,x)$with $x(t_0) = x_0$. Numerical solution in the fourth-order Runge-Kutta method with the following formula

$$t_{n+1} = t_n + h$$
$$x_{n+1} = x_n + \frac{1}{6}(k_1 + 2\,k_2 + 3k_3 + k_4) \quad (1)$$

with n = 0.1 , …
h is the step parameter

$$k_1 = hf(t_n, x_n)$$
$$k_2 = hf\left(t_n + \frac{h}{2}, x_n + \frac{k_1}{2}\right)$$
$$k_3 = hf\left(t_n + \frac{h}{2}, x_n + \frac{k_2}{2}\right) \quad (2)$$
$$k_4 = hf(t_n + h, x_n + k_3)$$

Let the solution to p the first order equation be$x_1(t), \ldots, x_p(t)$

$$x_1'(t) = f_1(t, x_1, x_2, \dots, x_p)$$
$$x_2'(t) = f_2(t, x_1, x_2, \dots, x_p)$$
$$\vdots$$
$$x_p'(t) = f_p(t, x_1, x_2, \dots, x_p) \quad (3)$$

With initial conditions $x_1(t_0) = {x_1}^0, x_2(t_0) = {x_2}^0, \dots, x_p(t_0) = {x_p}^0$

While the general form of the fourth-order Runge-Kutta method is

$t_{n+1} = t_n + h$ where h is the step parameter size

$$x_{n+1,i} = x_{n,i} + \frac{1}{6}\left(k_{1,i} + 2k_{2,i} + 2k_{3,i} + k_{4,i}\right) \quad (4)$$

$$k_{1,i} = hf_i(t_n, x_{n,1}, x_{n,2}, x_{n,3}, \dots, x_{n,p})$$
$$k_{2,i} = hf_i(t_n + \frac{h}{2}, x_{n,1} + \frac{k_{1,i}}{2}, x_{n,2} + \frac{k_{1,2}}{2}, \dots, x_{n,p} + \frac{k_{1,p}}{2})$$
$$k_{3,i} = hf_i(t_n + \frac{h}{2}, x_{n,1} + \frac{k_{2,i}}{2}, x_{n,2} + \frac{k_{2,2}}{2}, \dots, x_{n,p} + \frac{k_{2,p}}{2})$$
$$k_{4,i} = hf_i(t_n + h, x_{n,1} + k_{3,1}, x_{n,2} + k_{3,2}, \dots, x_{n,p} + k_{3,p}) \quad (5)$$

With $i = 1,2,3, \dots, p$

3. RESEARCH METHOD

The research method used is experimental research by designing a tool that can be used to produce fermented foods while monitoring pH, alcohol, glucose levels and temperature levels which are integrated in a *set of* tools called the *Temperature And Fermentation Controlled Chamber* (*TFCC)* with *Hybrid Systems* Technology . The next stage is to test the tool that has been designed and calibrate it to ensure that the tool functions optimally. The analysis stage is carried out through numerical method in accordance with the concept and flow of parametric and calculation development.

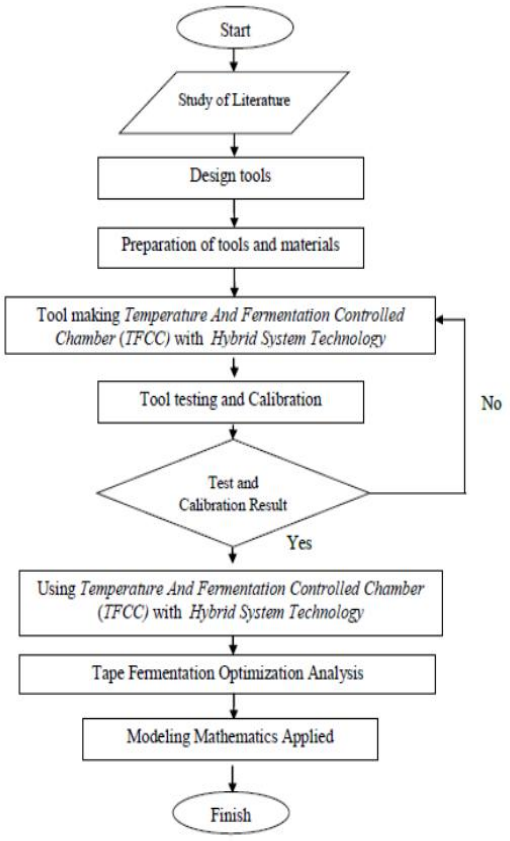
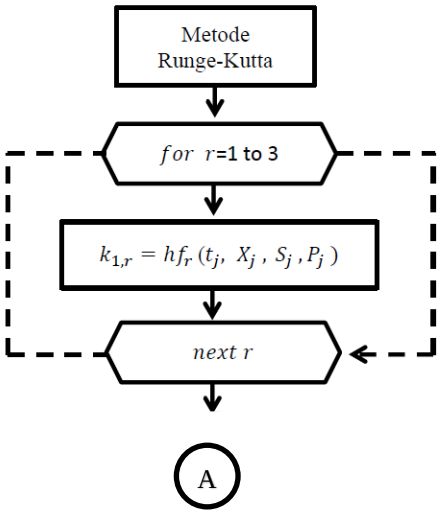


Figure 2. Research flow chart

schema of the fourth-order Runge-Kutta method analysis can be explained in the following plot (Figure 3).



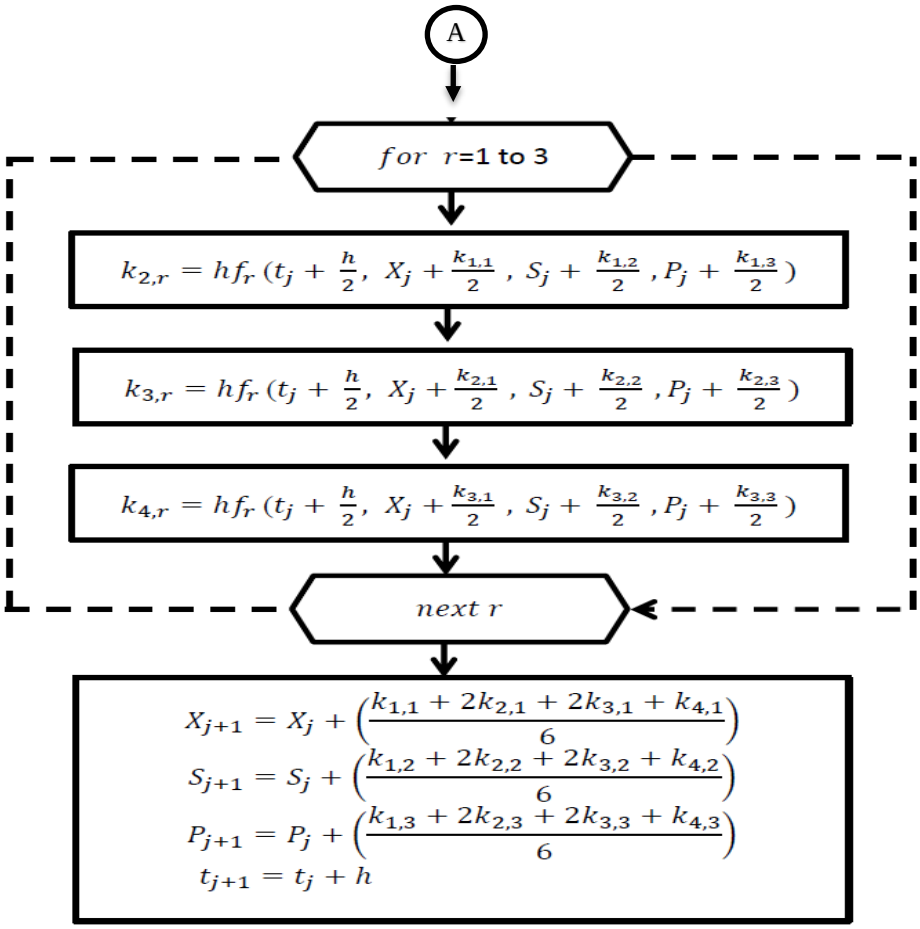


Figure 3. Flow chart of fourth order Runge-Kutta method

4. RESULT AND DISCUSSION

A Temperature And Fermentation Controlled Chamber TFCC with Hybrid System Technology , which is a production tool as well as monitoring the quality of fermented food, both the level of maturity, the degree of acidity, the degree of glucose and alcohol.

Figure 4. Making process of TFCC

The TFCC with hybrid system technology is equipped with an automated system accompanied by sensors that detect food quality and can be directly observed through the LCD screen integrated on the device. After welding and checking every corner and component that has been integrated in an integrated manner, testing and calibration is carried out on the tool to ensure that the tool is functioning optimally. Alcohol fermentation measurements were carried out after the instrument calibration process and carried out with materials such as cassava which were processed to become tape with predetermined yeast. Cassava tape production process through *TFCC* with Hybrid System Technology which has been calibrated so that it can be used. The production process is carried out by processing the cooking of cassava in a tube which is heated through a heating process with a conductivity system. After a

certain temperature of cooked cassava which is monitored through a temperature sensor, then the ripe cassava is given yeast.

Analysis of Numerical Method

Let $X(t), S(t)$and $P(t)$ express the yeast concentration, ethanol concentration and sugar concentration produced in the fermentation process at time t. The variables and chemical changes can be constructed into equations with the following assumptions:

The growth rate of yeast cells can be viewed as the change in their concentration with time through the fermentation process up to a point t which can be expressed as

$$\frac{dX(t)}{dt} = \mu X(t), \qquad (1)$$

where μ is the coefficient of fermentation rate

Fermentation activity in yeast cells is triggered by the presence of many yeasts. The more the amount of yeast, the longer the fermentation process and the resulting ethanol concentration. The fermentation rate is assumed to be the growth rate which can mathematically be written

$$\mu = \frac{\mu_{maks}\, S(t)}{K_m + S(t)} \qquad (2)$$

where $\mu_{maks}$is the maximum fermentation rate and $K_m$is the constant value in the fermentation process. When the concentration $S = 0$is , then the rate $\mu = 0$is the condition where the yeast does not grow anymore.

From equations (1) and (2) can be substituted into a new equation

$$\frac{dX(t)}{dt} = \frac{\mu_{maks}\, S(t)\, X(t)}{K_m + S(t)} \qquad (3)$$

The rate of fermentation is also influenced by the limited amount of enzyme, so that the constant value is $K_m$changed toK_{xs}

$$\frac{dX(t)}{dt} = \frac{\mu_{maks}\, S(t)\, X(t)}{K_{xs} + S(t)} \qquad (4)$$

At the maximum concentration of yeast, it will inhibit the activity of enzymes that cause cells to lose *lysis* and eventually die. In the equation using a *non-competitive inhibition model* so that the growth rate of yeast cells in the fermentation process after an obstacle is stated by K_{ix}stating the inhibition constant by the enzyme.

$$\frac{dX(t)}{dt} = \frac{\mu_{maks}\, S(t)\, X(t)}{K_{xs} + S(t)} \times \frac{K_{ix}}{K_{ix} + S(t)} \qquad (5)$$

In equation (6.5) it is influenced by the high sugar concentration resulting from the sugar concentration before it is inhibited P_{ix}, with the maximum sugar concentration P_{mx}so that the yeast concentration rate in the fermentation process is:

$$\frac{dX(t)}{dt} = \frac{\mu_{maks}\, S(t)\, X(t)}{K_{xs} + S(t)} \times \frac{K_{ix}}{K_{ix} + S(t)} \times \frac{P_{mx} - P(t)}{P_{mx} - P_{ix}} \qquad (6)$$

Mean while, for the growth rate of ethanol in the fermentation process by $q_{s,maks}$stating the specific enzyme rate and K_{ss}stating the limiting constant of the enzyme, we get the equation

$$\frac{dS(t)}{dt} = -\frac{q_{s,maks}\, S(t)\, X(t)}{K_{ss} + S(t)} \qquad (7)$$

With the same method in equations (2), (2) to (6), then we get

$$\frac{dS(t)}{dt} = -\frac{\mu_{maks}\, S(t)\, X(t)}{K_{ss} + S(t)} \times \frac{K_{is}}{K_{is} + S(t)} \times \frac{P_{ms} - P(t)}{P_{ms} - P_{is}} \qquad (8)$$

Through the completion of a system of non-linear ordinary differential equations, it can be obtained the equation for the growth rate in the fermentation process as follows:

$$\frac{dX(t)}{dt} = \frac{\mu_{maks}\, S(t)\, X(t)}{K_{ss} + S(t)} \times \frac{K_{ix}}{K_{ix} + S(t)} \times \frac{P_{mx} - P(t)}{P_{mx} - P_{ix}}$$

$$\frac{dS(t)}{dt} = -\frac{\mu_{maks}\, S(t)\, X(t)}{K_{ss} + S(t)} \times \frac{K_{is}}{K_{is} + S(t)} \times \frac{P_{ms} - P(t)}{P_{ms} - P_{is}}$$

$$\frac{dP(t)}{dt} = \alpha \frac{d\,X(t)}{dt}\left[\frac{q_{maks}\, S(t)\, X(t)}{K_{sp} + S(t)} \times \frac{K_{ip}}{K_{ip} + S(t)} \times \frac{P_{mp} - P(t)}{P_{mp} - P_{ip}}\right] \qquad (9)$$

system of non-linear ordinary differential equations, then the equation for the growth rate in the fermentation process in the second model can be obtained

$$\frac{dX(t)}{dt} = \frac{\mu_{maks}\, S(t)\, X(t)}{K_{xx} + S(t)} \times \frac{K_{ix}}{K_{ix} + S(t)} \times e^{\frac{-P(t)}{K_{px}}} - K_d X(t)$$

$$\frac{dS(t)}{dt} = -\frac{q_{s,maks}\, S(t)\, X(t)}{K_{ss} + S(t)} \times \frac{K_{is}}{K_{is} + S(t)} \times e^{\frac{-P(t)}{K_{ps}}}$$

$$\frac{dP(t)}{dt} = \alpha \frac{d\,X(t)}{dt}\left[\frac{q_{p,maks}\, S(t)\, X(t)}{K_{sp} + S(t)} \times \frac{K_{ip}}{K_{ip} + S(t)} \times e^{\frac{-P(t)}{K_{pp}}}\right] \qquad (10)$$

The values for the initial conditions and parameters used in the first model are given in Table 1.

Table 1. Initial requirements of the fermentation model

Initial concentration (X_0)	Initial concentration (S_0)	Initial concentration (P_0)
10 g/lt	0.2 g/lt	0
20 g/lt	0.2 g/lt	0
30 g/lt	0.2 g/lt	0

40 g/lt	0.2 g/lt	0
50 g/lt	0.2 g/lt	0

While the parameter values of the fermentation model are obtained in Table 2.

Table 2. Parameter values of fermentation model

Yeast cell growth model	
μ_{max} $^{-1}$ hour)	1.15
K_{ix}(g/lt)	300
S_{sx}(g/lt)	1.35
P_{ix}(g/lt)	1.42
P_{mx}(g/lt)	48.9
Ethanol growth model	
$q_{s,max}$(g product.hours $^{-1}$)	3.50
K_{is}(g/lt)	1.45
S_{ss}(g/lt)	2.10
P_{is}(g/lt)	48.0
P_{ms} (g/lt)	95.5
Sugar Production Model	
α (g produk .jam^{-1})	0.42
$q_{p,max}$ (g product.hour^{-1})	3.05
K_{ip} (g/lt)	145
S_{sp} (g/lt)	2.06
P_{ip} (g/lt)	48.0
P_{mp} (g/lt)	95.5

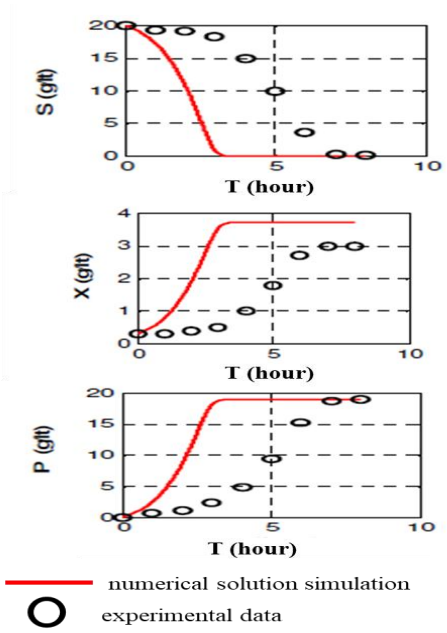


Figure 7. Numeric solution for X(t), S(t) and P(t)

5. CONCLUSION

From the numerical explanation, it can be seen that when t is small, the rate of yeast development in the fermentation process will be small, the number of yeast cells is still small. As a result, the growth rate will be slow. This can be seen from the graph of the increase in X(t) and P(t) as well as the graph of S(t) which is still slow. The greater the time t, the rate of yeast consumption is also greater because the number of yeast cells is also increasing. As a result, the growth rate of ethanol and sugar is also large. This can be seen from the graph of an increase in X(t) and P(t) as well as a graph of a faster decline in S(t). When the maximum consumption rate is reached, then the values of X(t), S(t) and P(t) are constant. The amount of concentration in the resulting ethanol is close to the initial concentration of sugar produced.

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