Mathematical Model of Crackers Quality Changes During Recondition

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Abstract. Crackers are a processed product that is much favored by the people of Indonesia. Crackers after frying have crunchy physical properties, however, if not stored properly the product is easy to change its physical properties, namely crackers become not crunchy or sluggish (mlempem). The change in crackers to "mlempem" can be understood because fried crackers have hygroscopic properties or easily absorb water. This study aims to examine changes in the quality of crackers during reconditioning, and the changes that occur are quantified in the form of a mathematical model. In this study, what is meant by reconditioning is an action to return the sluggish cracker to a crispy cracker. The quality of crackers is largely determined by the level of crispness. The physical properties of crackers that affect the level of crispness are water content, stress and strain. The research was conducted in a laboratory using ingredients in the form of crackers fried in sand (without oil) made from tapioca starch. The equipment used includes a stress and strain gauge (Universal Testing Machine), oven, analytical balance, sand fryer, tachometer, hygrometer, thermocouple, interface, data logger, and computer. The results of the study obtained a mathematical model of changes in the quality of crackers during reconditioning, which included reconditioning of moisture content, stress, and strain.

Keywords: frying · quality of crackers · physical properties · reconditioning

1 Introduction

Crackers are food products which are processed by frying. Frying is a unique cooking process, interesting, and lots of variety of food cooked with that way. The frying process takes place through contact of food material with heat-conducting medium involving heat transfer by conduction and convection and carried out at a high temperature (180 °C–220 °C). Frying has been practicing in cooking food but the process has not yet thoroughly studied and published [6, 10, 14].

Crackers can easily absorb moisture from the environment as it has hygroscopic characteristic. Absorption of moisture by the crackers will cause changes on its moisture content, stress, and strain simultaneously. The changes will lead to decrease of the crackers quality and the crackers become "sluggish" that are no longer having economic

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value [12, 13, 16, 17]. As crackers is one of most favorite food in Indonesia, a study on quality changes of crackers due to moisture absorption would give greater benefits to the cracker producers (both small scale producers and industrial scale producers) in avoiding profit loss.

This study was focused on recondition of sluggish crackers to get better crispiness quality. For this purpose, sand-fried crackers in a sluggish state were reconditioned by heating to increase crispness. On heating process heat and water mass transfer occurs simultaneously. The heat will be transferred from the environment into the material, and at that time the water in the material due to the heat energy will be transferred out of the surface of the material, followed by evaporation of water from the surface of the material into the ambient air [1–3, 7, 8, 14, 15]. Experiments were made to develop a mathematical model of changes in the quality parameters of crackers during reconditioning, which include (moisture content, stress, and strain). It was expected that the mathematical model could be used as tool for developing method in maintaining quality of crackers during storage.

2 Materials and Methods

The research was conducted using laboratory experimental methods. The research site is in the Agricultural Technology Laboratory, Jenderal Sudirman University, Purwokerto.

2.1 Materials and Tools

The material used in this study consisted of fried sand crackers that had been stored in an open space (without being packaged) for 13 h. During storage, the crackers experienced an average increase in water content from 3.3% on a dry basis to 11.3% on a dry basis.

The equipment used in the research consists of:

a. Cracker fryer with sand.
b. Temperature measuring devices include: Thermocouples, data loggers, interfaces, and computers.
c. Water content measuring devices (oven, analytical balance, desiccator, and stop watch), as well as stress and strain measuring devices (universal testing machine).

2.2 Laboratory Experiments

Moisture content is one indicator that can be used to measure the level of crispness of crackers. Crispy crackers when chewed can be ascertained that the water content is low, and soft crackers can be ascertained to have high moisture content [9, 13]. However, crackers with low water content are not necessarily crunchy, so using the water content indicator alone is not enough to detect the crunchiness of the crackers. For this reason, other quantitative indicators are needed to measure the level of crispness, and in this study quantitative values of stress and strain were used [4, 11].

Stress and strain are physical quantities of materials needed as indicators to determine the level of crispness of crackers. The smaller the value of the stress and strain of the crackers, it can be ascertained that the crackers are getting crunchy.

Laboratory experiments carried out in this study include: measurement, calculation, mathematical model development, and model validation. The mathematical model of changes in product quality parameters during reconditioning is as follows:

a. For moisture content:

$$\frac{dM}{d\theta} = -K_{MR}(M - M_{min}) \tag{1}$$

$$\left(\frac{M_\theta - M_{\min}}{M_i - M_{\min}}\right) = \exp(-K_{MR}.\theta) \tag{2}$$

where:

M = Moisture content (% dry basis)

KMR = constant change in moisture content during reconditioning (% dry basis/hour)

θ = recondition time (hours)

b. For stress:

$$\left(\frac{\sigma_\theta - \sigma_{\min}}{\sigma_i - \sigma_{\min}}\right) = \exp(-K_{\sigma R}.\theta) \tag{3}$$

where:

σ = stress (N/mm^2)

KσR = constant change of stress during recondition (N/mm^2)/hour

c. For strain:

$$\left(\frac{\varepsilon_\theta - \varepsilon_{\min}}{\varepsilon_i - \varepsilon_{\min}}\right) = \exp(-K_{\varepsilon R}.\theta) \tag{4}$$

ε = strain (mm/mm)

$K_{\varepsilon R}$ = constant change of strain during recondition (mm/mm)/hour

The product parameter rate constant (K) obtained from the above calculation results depends on the process temperature. The rate constant of change is expressed by the Arrhenius equation as follows:

$$K = B.exp\left(\frac{-Ea}{R.T}\right) \tag{5}$$

where:

K = constant of quality parameter change.

B = frequency factor (0K-1).

Ea = activation energy (kJ/mole.0K).

R = ideal gas constant = 8.314 kJ/mole.^{0}K.

T = temperature (^{0}K).

Table 1. The results of measuring the moisture content of crackers against temperature and reconditioning duration (T45C, RH 32%; T 40C, RH 35%, T 35C, RH 55%)

Time	Moisture content (%) dry basis (observation)		
(hour)	T 35C	T 40C	T 45C
0	11.3	11.3	11.3
0.5	8.9	8.5	8.2
1.0	7.3	6.7	6.2
1.5	6.0	5.5	4.9
2.0	5.3	4.7	4.0
2.5	4.7	4.1	3.5
3.0	4.4	3.8	3.2
8.0	3.6	3.1	2.5
12	3.5	3.0	2.5

Table 2. Constant changes in moisture content during reconditioning (K_{MR})

T (C)	T (Kelvin)	KMR	1/T (Kelvin)	ln (K_{MR})
35	308	0.7533	0.003247	−0.28329
40	313	0.8157	0.003195	−0.20371
45	318	0.8645	0.003145	−0.14560

3 Results and Discussions

3.1 Moisture Content

Results of experiments indicated that the crackers produced by sand-frying at a process temperature of 200 C with a frying time of 70 s, have a moisture content of about 3.3% on a dry basis with a crunchy texture, a stress value of 0.105 N/m^2, and a strain value of 0.133 mm/mm. Under these conditions, if the crackers were in direct contact with the air (without being packaged) for 24 h, the moisture content of the crackers increased to about 11.3% on a dry basis, with a soft texture. The results of measuring the moisture content of crackers on the reconditioning time with several variations of the process temperature can be seen in Table 1 and Fig. 1.

It can be seen that during reconditioning, crackers undergo changes in water content that are getting smaller and smaller. The water content value after approaching the 12-h reconditioning time, has relatively not changed, so the 12-h reconditioning value is used as a reference for the minimum water content value for reconditioning.

The constant value of the change in moisture content with respect to temperature and duration of reconditioning (K_{MR}) was obtained by plotting the results of the measurement of water content (Table 1), using the equation for the rate of change of water content during reconditioning (Eq. 2). From the plotting results, it is obtained that the value of K_{MR} as a function of temperature can be seen in Table 2.

The K_{MR} value as a function of temperature is solved by the Arrhenius equation (Eq. 5), so that it is obtained:

$$K_{MR} = (60, 437)e^{-1349,6/(273+T_{rec})} \quad (6)$$

So the mathematical model for estimating changes in the moisture content of crackers during reconditioning is:

$$\left(\frac{M_\theta - M_{\min}}{M_i - M_{\min}}\right) = \exp\{(-60, 437)(e^{-1349,6/(273+T_{rec})})\theta\} \quad (7)$$

T_{rec} = recondition temperature (°C).

It can also be used to predict the processing time (θ) if the process temperature and water content are determined at the desired level of crispness, using the following mathematical model:

$$\theta = \frac{\ln\left(\frac{M_\theta - M_{\min}}{M_i - M_{\min}}\right)}{-60, 437e^{1349,6/(273+T_{rec})}} \quad (8)$$

Prediction results of changes in product moisture content during reconditioning using a mathematical model are considered quite good, with an average prediction error of 0.31%, and a standard deviation of 0.43%. Mathematical modelling of changes in water content during reconditioning in its application can be used to calculate the exact time required to reduce the water content to the desired time, if the reconditioning temperature is known. This model of changes in water content is very useful because one indicator of the level of crispness of crackers is the water content, in addition to stress and strain.

The process of reconditioning the moisture content is analogous to the drying process, the higher the temperature used, the faster the process of decreasing the moisture content of the material. This condition will also be experienced if the food is placed in an environment where the water content of the material is higher than the balanced water content, then the food will release water vapor until it reaches a balanced water content [5, 11]. The prediction results of the water content of fried sand crackers on the temperature and duration of reconditioning can be seen in Table 3, and Fig. 1.

3.2 Stress and Strain

Based on the results of the study, fried sand crackers at a temperature of 200 C for 70 s had an average stress of 0.105 N/mm^2 and a strain of 0.133 mm/mm, with a crunchy texture. Under these conditions, if the crackers are in direct contact with the outside air at a temperature of 28 C, and 80% RH for 24 h, the texture of the crackers changes to sluggish, with the stress value changing to 1.40 N/mm^2, and the strain 0.80 mm/mm. The soft nature of crackers can be reconditioned by heating or drying. The complete results of changes in stress and strain values during reconditioning can be seen in Table 4.

Table 3. Value of observation and prediction of moisture content of fried sand crackers during reconditioning

Time (hours)	Moisture content % dry basic (observation)			Moisture content % dry basic (prediction)		
	T 35 C	T 40 C	T 45 C	T 35 C	T 40 C	T 45 C
0	11.3	11.3	11.3	11.3	11.3	11.3
0.5	8.9	8.5	8.2	8.85	8.54	8.19
1.0	7.3	6.7	6.2	7.18	6.71	6.19
1.5	6.0	5.5	4.9	6.03	5.49	4.89
2.0	5.3	4.7	4.0	5.25	4.67	4.04
2.5	4.7	4.1	3.5	4.71	4.13	3.50
3.0	4.4	3.8	3.2	4.34	3.77	3.14
8.0	3.6	3.1	2.5	3.56	3.05	2.50
12	3.5	3.0	2.5	3.54	3.04	2.49

Table 4. Measurement results of changes in stress (σ) and strain (ε) during reconditioning (at T 45C, RH 32%; T 40C, RH 40%; T 35C, RH 55%)

Time (hours)	T 45C		T 40C		T 35C	
	Stress (N/mm^2)	Strain (mm/mm)	Stress (N/mm^2)	Strain (mm/mm)	Stress (N/mm^2)	Strain (mm/mm)
0	1.40	0.80	1.40	0.80	1.40	0.80
0.5	0.94	0.57	1.00	0.61	1.05	0.65
1.0	0.61	0.42	0.70	0.48	0.81	0.53
1.5	0.45	0.33	0.51	0.38	0.62	0.45
2.0	0.33	0.26	0.39	0.31	0.49	0.39
2.5	0.25	0.23	0.31	0.27	0.39	0.35
3.0	0.21	0.21	0.26	0.25	0.35	0.31
5.0	0.15	0.17	0.17	0.19	0.21	0.22
12	0.14	0.16	0.15	0.17	0.16	0.18

From the measurement results (Table 4) it can be seen that during the reconditioning, the crackers experience changes in stress and strain which are getting smaller and smaller. Changes in stress and strain values for a duration of 5 to 12 h did not change much, so the 12 h reconditioning time was used as a reference for the minimum stress and strain values during reconditioning.

The value of the constant change with temperature and the length of reconditioning for stress ($K_{\sigma R}$), and strain ($K_{\varepsilon R}$), obtained by plotting the graph of the results of stress

Table 5. Constant of change in stress and strain as a function of absolute temperature

T (C)	T (Kelvin)	1/TKelvin	Stress		Strain	
			KσR	ln ($K_{\sigma R}$)	KεR	ln ($K_{\varepsilon R}$)
35	308	0.00325	0.65	-0.431	0.53	-0.636
40	313	0.00319	0.82	-0.201	0.73	-0.319
45	318	0.00314	0.96	-0.040	0.90	-0.106

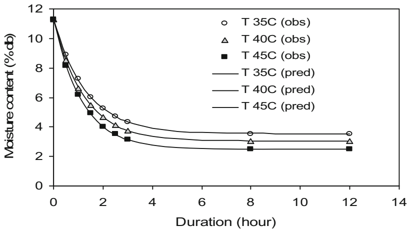

Fig. 1. Observation and prediction value of crackers fried sand during recondition.

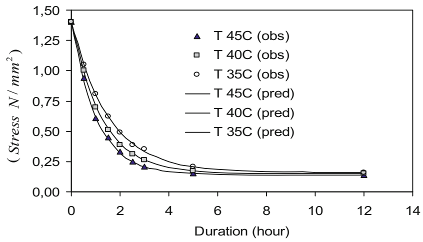

Fig. 2. Observation and prediction values of cracker stress during reconditioning.

and strain measurements (Table 4), using the equation for the rate of change of stress (Eq. 3), and the rate of change of strain (Eq. 4). From the plotting results, it is found that the values of $K_{\sigma R}$ and $K_{\varepsilon R}$ as a function of temperature can be seen in Table 5.

The values of $K_{\sigma R}$ and $K_{\varepsilon R}$ as a function of temperature are solved by the Arrhenius Equation (Eq. 5), so that the following values are obtained:

$$K_{\sigma R} = (1,686E + 05)e^{-3836,4/(273+T_{rec})} \tag{9}$$

$$K_{\varepsilon R} = (1,144E + 07)e^{-5196,9/(273+T_{rec})} \tag{10}$$

So the mathematical model for predicting the change in stress and strain during reconditioning can be written as follows:

a. For stress:

$$\left(\frac{\sigma_\theta - \sigma_{\min}}{\sigma_i - \sigma_{\min}}\right) = \exp((-1,686x10^5)e^{-3836,4/(273+T_{rec})}\theta)) \tag{11}$$

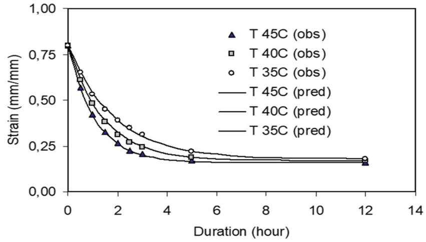

Fig. 3. Observation and prediction values of cracker strain during reconditioning.

b. For strain:

$$\left(\frac{\varepsilon_\theta - \varepsilon_{\min}}{\varepsilon_i - \varepsilon_{\min}}\right) = \exp((-1,144x10^7)e^{-5196,9/(273+T_{rec})}\theta)) \tag{12}$$

Prediction results of changes in product stress and strain during reconditioning using mathematical models obtained are considered quite valid because they have a small error rate. The average prediction for stress is 1.60% with a standard deviation of 2.16%, while the mean prediction error for strain is 1.22% with a standard deviation of 1.71%.

Another form of stress and strain model that can also be used to calculate the exact time of the reconditioning process (θ) to reduce stress (σ), and strain (ε) to restore the desired level of crispness of crackers, with the following mathematical model:

$$\theta = \frac{\ln\left(\frac{\sigma_\theta - \sigma_{\min}}{\sigma_i - \sigma_{\min}}\right)}{(-1,686x10^5)e^{-3836,4/(273+T_{rec})}} \tag{13}$$

$$\theta = \frac{\ln\left(\frac{\varepsilon_\theta - \varepsilon_{\min}}{\varepsilon_i - \varepsilon_{\min}}\right)}{(-1,144x10^7)e^{-5196,9/(273+T_{rec})}} \tag{14}$$

Mathematical modeling of stress and strain changes during reconditioning, in its application can be used to determine the exact temperature and time required to reduce stress and strain to the desired level. This stress and strain change model is very useful, because one indicator of the crispness of crackers is the stress and strain. Crackers with small stress and strain values can be ensured that the texture is crispy. The results of the study concluded that crackers were said to be crunchy to very crispy if the stress value was ≤ 0.16 N/mm^2 and the strain was ≤ 0.175 mm/mm [11].

The complete results of observations and predictions for cracker stress and strain with respect to temperature and reconditioning time can be seen in Fig. 2 and Fig. 3.

4 Conclusion

1. The average error rate prediction of cracker moisture content during the reconditioning process was 0.31% with a standard deviation of 0.43%. The moisture content of the crackers during the reconditioning decreased quite rapidly at the beginning of the process, and then slowed down after 3 h of the reconditioning process. The

higher the process temperature will result in a faster rate of temperature decline, and will result in a lower balance moisture content. The reconditioning process time for reducing moisture content can be modeled by the following mathematical equation:

$$\theta = \frac{\ln\left(\frac{M_\theta - M_{\min}}{M_i - M_{\min}}\right)}{-60,437e^{1349,6/(273+T_{rec})}}$$

2. The average error rate of cracker stress prediction during the reconditioning process was 1.60% with a standard deviation of 2.16%. The cracker stress during reconditioning experienced a fairly rapid rate of decline at the beginning of the process, and then slowed down and headed to a constant stress value after 5 h of the reconditioning process. The higher the process temperature, the faster the rate of stress value drop. The reconditioning process time for stress reduction can be modeled by the following mathematical equation:

$$\theta = \frac{\ln\left(\frac{\sigma_\theta - \sigma_{\min}}{\sigma_i - \sigma_{\min}}\right)}{(-1,686x10^5)e^{-3836,4/(273+T_{rec})}}$$

3. The average error rate of cracker strain prediction during the reconditioning process was 1.22% with a standard deviation of 1.71%. The cracker strain during reconditioning experienced a fairly rapid decrease at the beginning of the process, and then slowed down and headed to a constant strain value after 5 h of the reconditioning process. The higher the process temperature, the faster the rate of strain reduction will be. The reconditioning process time for strain reduction can be modeled by the following mathematical equation:

$$\theta = \frac{\ln\left(\frac{\varepsilon_\theta - \varepsilon_{\min}}{\varepsilon_i - \varepsilon_{\min}}\right)}{(-1,144x10^7)e^{-5196,9/(273+T_{rec})}}$$

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