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MODELING AND ON-LINE PROCESS IDENTITICATION OF GMS FLAKE SHAPING PROCESS USING RDF

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INTISARI

Gliserol Monostearat (GMS) adalah sejenis surfaktan yang dapat dibuat dari turunan minyak sawit. Pembuatan GMS melibatkan proses pembentukan serpihan di mana GMS dalam bentuk bubur panas dimasukkan ke Rotary Drum Flaker (RDF) untuk dibentuk menjadi serpihan. Pada makalah ini diusulkan sebuah model dinamika yang mengekspresikan proses tersebut dan cocok untuk rekayasa kontroler menggunakan pendekatan ekspresi discrete, dan dibuat algoritma identifikasi on-line untuk mengestimasi nilai parameter. Studi simulasi dilakukan untuk mengevaluasi model yang diusulkan yang memiliki kemampuan identifikasi proses on-line.
Kata kunci: *Gliserol Monostearat, surfaktan, minyak sawit, Rotary Drum Flaker, model dinamika, identifikasi proses on-line.*

ABSTRACT

Glycerol Mono Stearic (GMS) is a kind of surfactant which can be made from derivatives of Crude Palm Oil (CPO). Making GMS involves flake shaping process where GMS which takes form of hot slurry is fed into a rotary drum flaker (RDF) to be shaped into flakes. In this paper, a dynamical model which represents the process as well as suitable for controller design is proposed using discrete approach, and on-line process identification algorithm is made to estimate model parameter values. Simulation study was conducted to evaluate the proposed model which has on-line process identification capability.
Keywords: *Glycerol Mono Stearic, surfactant, CPO, Rotary Drum Flaker, dynamical model, on-line process identification.*

1 INTRODUCTION

Glycerol Mono Stearic (GMS) is non-ionic surfactant which is commonly used in shampoo as pearlizing agent, emulsifier and lotion, and also in food as opacifier such as in ice cream and butter [1][2]. GMS can be made from derivatives of Crude Palm Oil through esterification reaction [2]. After reaction and purification, GMS is shaped to become flake or powder. In industry, to make powder or flake, steam heated rotary drum dryers are already used to process food such as cereal (infant food), tapioca starch, etc., chemical such as detergent, DDT, etc., and other materials such as fish meal, seaweed extract, yeast etc.[3]. These already existing rotary drum dryers function to remove water and/or solvents from solution, slurry or suspension, through evaporation. Wuryaningsih and Adin et.al. proposed flake shaping process of GMS using water cooled rotary drum, named Rotary Drum Flaker (RDF) [4]. It functions to make flake from slurry of GMS by removing heat from GMS. Up to the present, there has been no academic paper/report that deals with modeling and on-line identification of GMS flake shaping process using RDF.

This research addresses modeling and on-line parameter identification in flake shaping process of GMS using RDF. The purpose is to build a dynamical model of the process and to determine parameter values during the process. These model and parameter values will be used to design a controller in order to keep good quality of GMS.

This paper is organized as follows. Section 2 summarizes the process of flake shaping. Section 3 explains the proposed dynamical model, and section 4 is about on-line identification. Section 5 presents computer simulation, and Section 6 is conclusion.

2 PROCESS DESCRIPTION

During the stage of purification in the GMS production process, impurities are separated from GMS. After purification, GMS which takes form of hot slurry is ready to be fed into RDF to be shaped into flakes. The following figure 1 shows the RDF used in this research [4]. The purpose of the RDF is to make slurred GMS become hard and crispy by taking its heat out. First, slurred GMS is fed into the feed-tray right below the drum. As the RDF rotates at angular speed of $\dot{\theta}$ [rad/sec], the slurred GMS is moved along the surface of the RDF from the initial point where its temperature is T_s [ºC] to the end point where its temperature is T_e [ºC]. When the slurred hot GMS is moved, its heat is absorbed by the cooling water inside the drum and the room air outside the drum. As the GMS reaches the end point it is peeled off the surface of the drum by a knife, and then fed into the crusher to be crushed into small flakes.

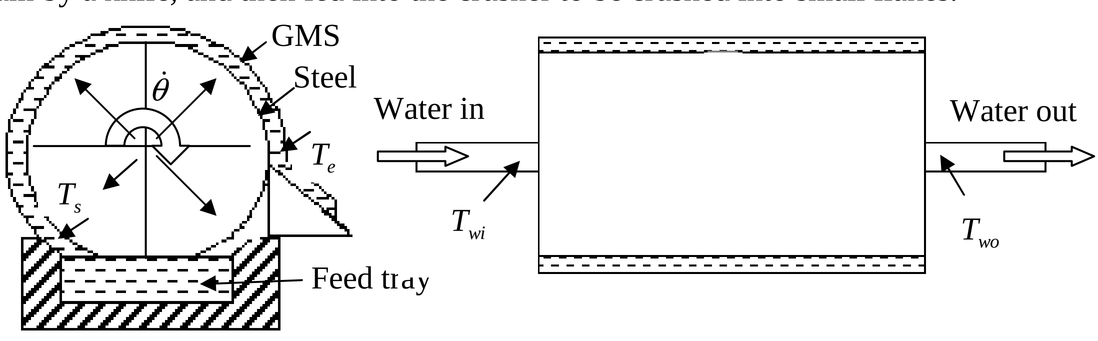

Figure 1. Rotary Drum Flaker Used in Flake Shaping Process of GMS.

Figure 2 shows a photo of RDF used in this research. It has the diameter of 120 cm, the length of 118cm, and the thickness of the steel of 4 mm. The drum is made of stainless steel SS304 whose physical parameter values are: thermal conductivity $\lambda_s = 53.5$ [W/m.K],heat coefficient $c_s = 465$ [J/kg.K],mass density $\rho_s = 7830$ [kg/m^3].

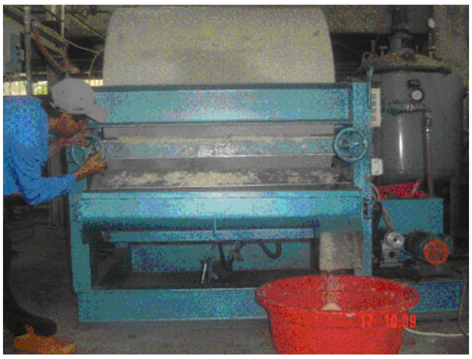

Figure 2. Photo of RDF.

The dwelling time of GMS on the drum surface is given by:

$$t_e = \frac{\theta_e - \theta_i}{\dot{\theta}} \text{ [second]} \qquad (1)$$

Where: θ_i [rad] is angular position of initial temperature of GMS T_s [ºC], θ_e [rad] is that of final temperature T_e [ºC]. It is assumed that θ_i =-225 [Degree] and θ_e =0 [Degree], while the value of $\dot{\theta}$ [rad/sec] depends on the required amount of GMS per unit time which is produced by the RDF, namely the productivity of GMS that is denoted as Ω [kg/sec]. The relationship between productivity and rotational angular of RDF is given as follows.

$$\dot{\theta} = \frac{2\pi}{d \times L \times R_2 \times \rho_{gms}} \Omega \qquad (2)$$

where d [m] is the thickness of GMS on the drum surface.

3 DYNAMICAL MODEL

Dynamical model of the system is combination of dynamical model of the chiller and dynamical model of the RDF.

[Dynamical model of the chiller]

The end temperature of GMS T_e [ºC] is subject to the cooling water temperature at the inlet of the RDF T_w [ºC]. Since the cooling water is supplied by a chiller, the cooling water temperature is determined by the reference temperature applied to the chiller T_r [ºC]. The RDF is located separately from the chiller in a distance of several meters and the cooling water is supplied from the chiller to the RDF through pipes. Therefore, it is assumed there exists a dead time in the dynamics. Moreover, the existing local controller attached to the chiller can be adjusted so that the dynamics of the chiller itself can be assumed to have the form of a one order lag. Combined these assumptions, the dynamics from T_r [ºC] to T_w [ºC] can be represented by a one order lag with a dead time as follows.

$$T_w(s) = \frac{e^{-L_1 s}}{\alpha_1 s + 1} T_r(s) \qquad (3)$$

where: s denotes the Laplace variable, α_1 is the time constant of the chiller, and L_1 is the dead time of the chiller. Figure 3 shows a time response of cooling water temperature T_w [ºC] towards a step reference temperature which changes from initial temperature of 30 [ºC] to 25 [ºC]. It responses with time constant of 10 [sec] and dead time of 1 [sec].

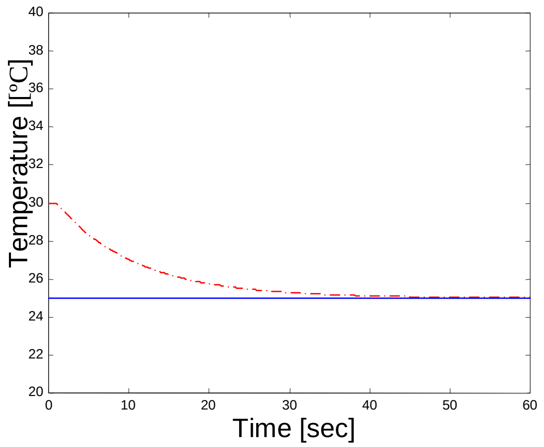

Figure 3. Temperature Dynamics of the Chiller
[Dotted line: Temperature of cooling water, solid line: reference temperature]

[Dynamical model of the RDF]

Figure 4 shows temperature history of GMS obtained through temperature numerical analysis [5].

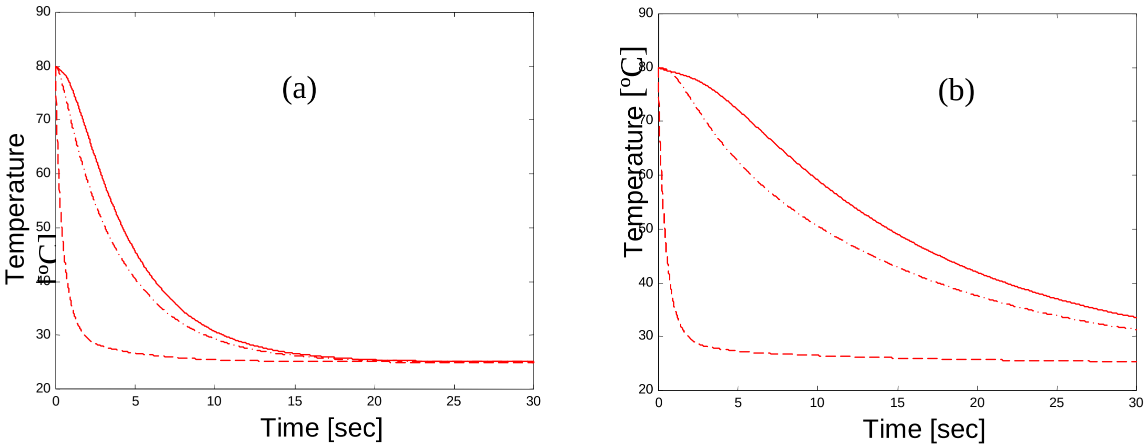

Figure 4. GMS Temperature History. [(a).Thickness 2 [mm], (b) Thickness 4 [mm]]

Figure 4 (a) is the temperature of which the thickness of GMS is 2 [mm], while figure 4 (b) is the temperature of which the thickness of GMS is 4 [mm]. The initial temperature of GMS is uniformly 80 [ºC], and the cooling water temperature is 25 [ºC]. The room air temperature is 25 [ºC] in figure 4 (a) and 30 [ºC] in figure 4 (b). Solid line denotes the temperature history of the outer surface of GMS facing the room temperature, dotted line denotes the temperature history at the middle layer of GMS, and the broken line is the temperature history of the inner surface of GMS which is in contact with outer surface of the drum steel. In this research, temperature at the middle layer of GMS is selected to represent the dynamics of GMS temperature. By observing the results shown in figure 4, the dynamics governing the relationship from cooling water temperature T_w to GMS temperature T_p is approximated by the following transfer function.

$$T_p(s) = \frac{\beta_2 e^{-L_2 s}}{\alpha_2 s + 1} T_w(s) \quad (4)$$

where: s denotes the Laplace variable, α_2 is the time constant of the RDF, β_2 is the steady state gain of the RDF, and L_2 is the dead time of the RDF.

[Dynamical model of the system]

To see time response of the dynamical model of the total system, that is, the combined plant between the chiller and the RDF, the response in figure 3 is applied to the RDF to obtained simulation results shown in figure 5. The initial temperature of GMS is uniformly 80 [ºC], the cooling water temperature is 25 [ºC], and the room air temperature is 30 [ºC]. Figure 5 (a) is the temperature of which the thickness of GMS is 2 [mm], while figure 5 (b) is the temperature of which the thickness of GMS is 4 [mm].

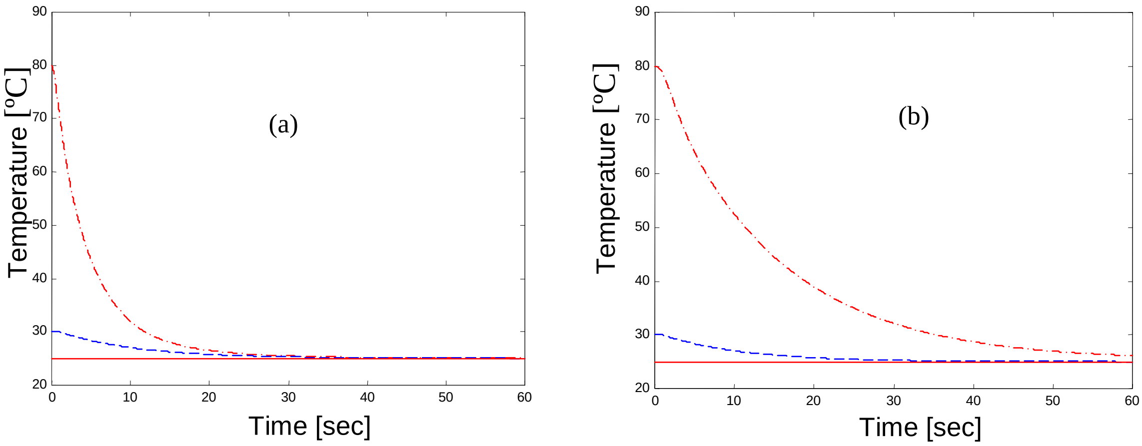

Figure 5. Temperature History of The Combined Dynamics (Chiller + RDF)

From these results, in this paper, the dynamics of the combined plant between the chiller and the RDF is proposed to be represented in discrete time expression as follows.

$$T_p(k) = \frac{b_{t0} q^{-D_t}}{1 - a_{t1} q^{-1} + a_{t2} q^{-2}} T_r(k) \quad (5)$$

where: k is time counter where k means the time is $k \times dt$ where dt is sampling time, q is a time delay operator whose meaning is $q^{-1} T_p(k) = T_p(k-1)$. b_{t0}, a_{t1}, a_{t2} are parameters of the model, and D_t is dead time.

4 ON-LINE PARAMETER IDENTIFICATION

Taking into account the effect of noise $n(k)$, equation (5) reduces to the following equation.

$$T_p(k) = \frac{b_{t0} q^{-D_t}}{1 - a_{t1} q^{-1} + a_{t2} q^{-2}} T_r(k) + n(k) \quad (6)$$

By some manipulation of equation (6), the following equation can be obtained.

$$T_p(k) = a_{t1} T_p(k-1) - a_{t2} T_p(k-2) + b_{t0} T_r(k - D_{t1}) + w(k) \quad (7)$$

where: $w(k) = n(k) - a_{t1} n(k-1) + a_{t2} n(k-2)$.

Let

$$\left.\begin{aligned} \theta^T &= [a_{t1} \quad -a_{t2} \quad b_{t0}] \\ z^T(k) &= [T_p(k-1) \;\; T_p(k-2) \;\; T_r(k - D_{t1})] \end{aligned}\right\} \quad (8)$$

Then equation (7) can be expressed as follows.

$$T_p(k) = z^T(k) \theta + w(k) \quad (9)$$

The parameter values θ can be calculated using a set of measured data $T_p(k), T_r(k); (k = 1, 2, \cdots, N)$, based on the following performance index [6].

$$J = \sum_{k=1}^{N} w^2(k) \tag{10}$$

The estimated parameter values $\hat{\theta}$ is that which minimizes J (or, $\frac{\partial J}{\partial \theta} = 0$). Now, let

$$\left.\begin{aligned} Y_N^T &= [T_p(1) \quad T_p(2) \quad \cdots \quad T_p(N)] \\ W_N^T &= [w(1) \quad w(2) \quad \cdots \quad w(N)] \\ Z_N^T &= [z(1) \quad z(2) \quad \cdots \quad z(N)] \end{aligned}\right\} \tag{11}$$

then equation (9) can be expressed as follows.

$$Y_N = Z_N \theta + W_N \tag{12}$$

The estimated parameter values $\hat{\theta}$ is then given by

$$\hat{\theta} = (Z_N^T Z_N)^{-1} Z_N^T Y_N ; \qquad \det(Z_N^T Z_N) \neq 0. \tag{13}$$

or

$$\hat{\theta} = \left[\sum_{k=1}^{N} z(k) z^T(k)\right]^{-1} \sum_{k=1}^{N} z(k) T_p(k) \tag{14}$$

Equation (13) or (14) calculates estimated parameter values after completing measurement of N number of input and output signals. On the other hand, from the experience of operating the RDF, it may take hours from start to finish of operation where circumstance may change during this time which leads to change in real system dynamics. As a result, the identified parameter values may no longer be able to express the real dynamics. In this case, it is necessary to update parameter values during operation of RDF.

From equation (11), let define:

$$Y_{N+1} = \begin{bmatrix} Y_N \\ T_p(N+1) \end{bmatrix}, \qquad Z_{N+1} = \begin{bmatrix} Z_N \\ z^T(N+1) \end{bmatrix} \tag{15}$$

$$P(N) = [Z_N^T Z_N]^{-1}, \qquad q(N) = Z_N^T Y_N \tag{16}$$

Y_{N+1} is a vector (N+1,1), Z_{N+1} is a vector (N+1,1), $P(N)$ is a matrix (3,3), and $q(N)$ is a vector (3,1). Substitute (15) into (16) to obtain

$$P(N+1) = P(N) - P(N) \frac{z(N+1) z^T(N+1)}{1 + z^T(N+1) P(N) z(N+1)} P(N) \tag{17}$$

$$q(N+1) = Z_N^T Y_N + Z(N+1) T_p(N+1) \tag{18}$$

Analogy to eq.(13), from eqs.(17),(18) the estimated parameters can be obtained as follows.

$$\begin{aligned} \hat{\theta}(N+1) &= P(N+1) q(N+1) \\ &= \hat{\theta}(N) + K(N+1)[T_p(N+1) - z^T(N+1)\hat{\theta}(N)] \end{aligned} \tag{19}$$

where:

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$$\left.\begin{aligned} K(N+1) &= \frac{P(N)z(N+1)}{1+z^T(N+1)P(N)z(N+1)} \\ P(N+1) &= [I-K(N+1)z^T(N+1)]P(N) \end{aligned}\right\} \qquad (20)$$

For the sake of generality, N in equations (19) and (20) is replaced by k. Equation (19) is used to estimate parameter values of the proposed model in equation (5) in on-line manner.

5 COMPUTER SIMULATION

As the initial condition, the cooling water supplied by the chiller is 30 [ºC], the room temperature is 30 [ºC], and the GMS temperature is uniformly 80 [ºC]. At time 0 [s] the cooling water reference temperature of the chiller is changed from 30 [ºC] to 25 [ºC], and the identification algorithm starts working in on-line manner. Figure 6 (a) shows parameter values in time series from 0 [s] to 60 [s], where they are updated in a certain interval of time. This result is obtained when the thickness of GMS is 2 [mm]. To evaluate the validity of the proposed model and the above on-line identification algorithm, 6 sets of parameters of time 10 [s], 20 [s], 30 [s], 40 [s], 50 [s], and 60 [s] were selected and substituted into the model. Figure 6 (b) compares the time history of GMS temperature and time history of the output of the model using these selected 6 sets of parameters.

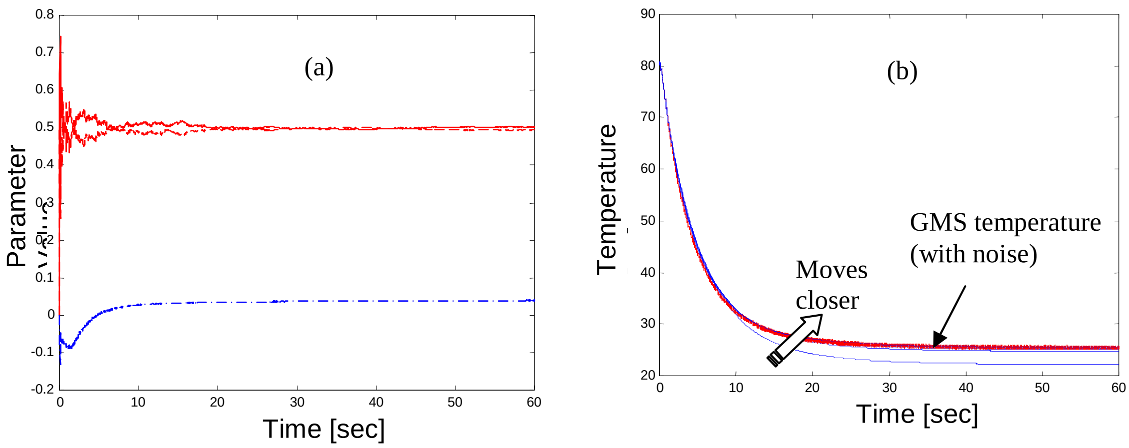

Figure 6. On-line Identification Result When GMS Thickness is 2 [mm]. [(a). Parameter values; (b). Time history of GMS temperature (noise disturbed signal), and identified model outputs (6 solid lines).

It can be seen that the model moves closer to the real GMS temperature with time. At time 60 [s], the following model was identified.

$$T_p(k) = \frac{0.0039z^{-5}}{1-0.5021z^{-1}+0.494z^{-2}}T_r(k) \qquad (21)$$

To evaluate the validity of the proposed model and the parameter identification algorithm against system dynamics change, the thickness of GMS was changed to 4 [mm], and a similar procedure as above was carried out. Figure 7 shows the parameter values and the time responses obtained.

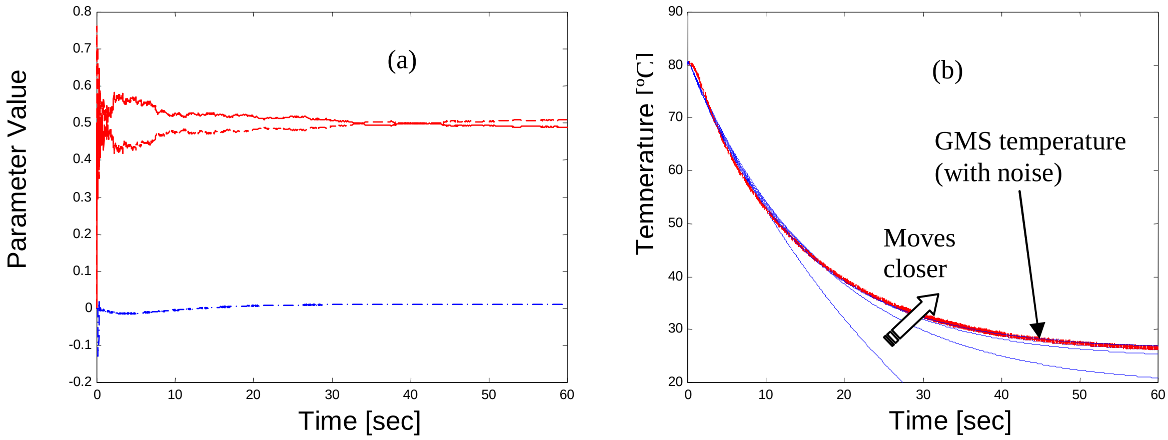

Figure 7. On-line Identification Result When GMS Thickness is 4 [mm].
[(a). Parameter values; (b). Time history of GMS temperature (noise disturbed signal), and identified model outputs (6 solid lines).

At time 60 [s], the following model was identified.

$$T_p(k) = \frac{0.0013z^{-20}}{1-0.54892z^{-1}+0.5096z^{-2}}T_r(k) \quad (22)$$

Similarly, it can be noted that the model output moves closer to the real GMS temperature with time.

6 CONCLUSION

From the results obtained in this paper, the following conclusion can be drawn:

1. The proposed dynamical model with on-line parameter identification capability represents well the dynamics of the system composed by the chiller and the RDF. The root mean square of estimation error of the result of which the GMS thickness is 2 [mm] (see figure 6.(b)) is 0.06 [ºC], while the root mean square of estimation error of which the GMS thickness is 4 [mm] (see figure 7.(b)) is 0.03 [ºC]. Both these values are substantially small compared with the operating temperature span which is between 25 [ºC] to 80 [ºC]. This demonstrates the validity of the model.

2. Speed of change of the relationship between input and output of the system against time affects precision of the estimated parameter values. The speed of change of the case when the GMS thickness is 2 [mm] experiences higher values during the first 20 minutes than that of the case when the GMS thickness is 4 [mm], and from conclusion 1 it is clear that the first case has higher estimation error than the second case.

3. When the speed of change is high the updating interval of parameter identification should be small. Conversely, when the speed of change is low, the updating interval of parameter identification can be set longer.

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