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Empirical Modelling of Pasteurization Process Using Plate Heat Exchanger

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Abstract

Pasteurization process is become the most important process especially in dairy and beverage industries. The aim of the process is to preserve the product quality and to extend the shelf life of product. The product temperature is a key parameter that must be controlled in order to maintain at desired value. Hence, in order to control process properly, an accurate process model needs to be developed. The objective of this study is to develop an empirical model of coconut milk pasteurization process using plate heat exchanger. The model was developed based on experimental data and represented in first order plus time delay (FOPTD) model. Overall, the obtained model gave good agreement with experimental data in validation result with maximum error is ±5%. The validation result showed that this model is suitable for use in control strategy for the further study.

Keywords: *Pasteurization, Empirical modelling, FOPTD model, process reaction curve*

1. Introduction

Coconut milk is the white liquid and contains of oil in water emulsion. It can be obtained by mechanical extraction of grated coconut meat with added water. It is very important ingredient for many food recipes of Asian and Pacific regions such as curry and deserts. It also become as a main ingredient in making of traditional cake. According to [1], coconut milk is complex biological fluid, typically contained about 54% moisture, 35% fat and 11% solid non-fat. In order to preserve the raw coconut milk, it must be pasteurized through heating process.

Pasteurization process is one of the food preservation techniques using thermal treatment and commonly applied in food product industry. The purpose of pasteurization is to eliminate pathogenic bacteria and vegetative organisms and as a result, the product can be extending their shelf life [2]-[3]. There are two methods of pasteurization currently used in industry namely batch and continuous processes. The batch process is a traditional method and involves many processes such as filling, heating, holding, cooling, emptying and cleaning. It is simple operation, flexible and easy to operate. However, the long period of heating process and small production has become the major drawback of this process [4]. For high production, the continuous process which is high temperature short time (HTST) is recommended because of more rapidly in heating process and can be minimized the energy consumption [5]. The HTST pasteurization consists of three stages viz. regeneration, heating and cooling sections. The crucial stage is heating process using heat exchanger to ensure unpasteurized product achieve desired pasteurization temperature before pass through holding tube and cooling sections. Prior to pasteurize food sample, the operation of equipment must be adequate to control the outlet food temperature in order to maintain at standard value.

In food processing industry, the process control plays an important part as it is vital to ensure several requirements are met such as product quality, energy consumption, production rate and safety the equipment and the process [6]. The important process parameter needs to be controlled in order to meet the desired requirement. For instance, in pasteurization process, the control of outlet pasteurization temperature from heat exchanger in heating section is a key element to avoid substantial change in properties product and to meet the industrial standard [7].

In order to implement a good performance of control strategy, it highly depends on dynamic process model to predict process behaviour [8]-[9]. Thus, it requires developing an accurately dynamic process model in order to use in process control strategy [10]. The process model can be developed by theoretical or empirical approach. However, theoretical approach is very complex due to all parameters need to be considered. Hence, the purpose of this paper is to develop empirical model of coconut milk pasteurization process. This obtained model will be used in process control strategy at next stage of study.

2. Materials and Methods

2.1 Experimental Works

The raw coconut milk purchased from local market was used in this study. The experiment was carried out using laboratory pasteurizer unit (Model Kholler Fe10, Malaysia) in order to determine the process model. The process diagram of this equipment is shown in Fig. 1. It was designed and fabricated by Noble Palms Sdn. Bhd., Malaysia. It utilises a three stages of plate heat exchanger for heating, regeneration and cooling processes. However, this study only focuses on heating process because it is a key section to ensure the product temperature achieved at desired value. The water is used as a heating medium. The flow rate of product was fixed at 1.5 ml/s.

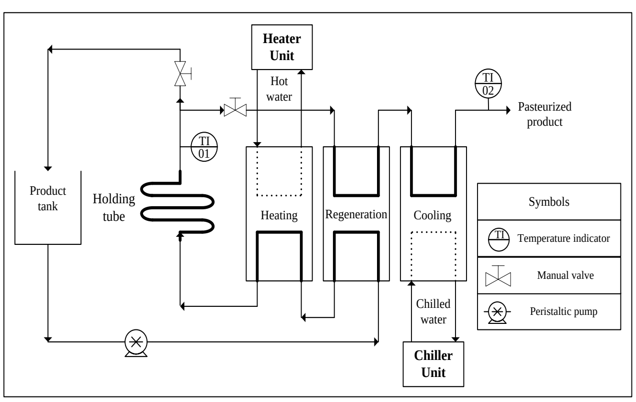

Fig. 1. Process diagram of laboratory pasteurizer unit

In this study, the hot water temperature and product temperature was chosen as manipulated and controlled variables, respectively. In order to determine the process model, a step change in hot water temperature was introduced from 70°C to 80°C at time = 5min. The response of product temperature was recorded until achieved at final steady state value. Three repetitions (E1, E2 and E3) were made for each experiment.

2.2 Process Modelling and Parameter Estimations

Generally, first order plus time delay (FOPTD) model is adequate to describe many dynamic processes accurately [11]. In control system design usually used FOPTD model in transfer function form as shown in (1) [6]. This model is represented in Laplace transform and can be converted in time domain equation as shown in (2). The symbols of K_p, θ and τ in this equation mean of process gain, time delay and time constant, respectively. Therefore, the predicted process model was fitted with FOPTD model. The experimental data were used in empirical process model development by plotted using cftool from MATLAB R2009a. The process model parameters were calculated using three methods namely M1, M2 and M3. The M1 is obtained from cftool result, while M2 and M3 are tangent method and two point method, respectively [12]-[13].

$$G(s) = \frac{K_p e^{-\theta s}}{\tau s + 1} \qquad (1)$$

$$g(t) = K_p M \left[1 - e^{-\left(\frac{t-\theta}{\tau}\right)}\right] + g(t_{ss}) \qquad (2)$$

2.3 Diagnostic Evaluation and Model Validation

Prior to study in process control strategy, the obtained process model needs to undergo diagnostic evaluation. The purpose of diagnostic evaluation is to determine the capability of process model fitted with experimental data. Finally, the model was validated with new set of data in order to ensure variation in operation does not significantly degrade model accuracy.

3. Results and Discussion

3.1 Process Modelling

Three experiments were conducted for obtain process reaction curve by introduced step change in hot water temperature. In order to develop process model, the experimental data were plotted using cftool from MATLAB R2009a. Then, the predicted model was developed empirically based on these data as shown in Fig. 2. This figure shows the dynamic product temperature after the hot water temperature was changed from 70°C to 80°C at time=5 min for all experiments. The trend of dynamic product temperature is similar for all replications of experiments. All dynamic responses of product temperature exhibit appropriate under FOPTD model. From Fig. 2, the final steady state value of product temperature is achieved the desired pasteurization temperature of coconut milk [14].

The predicted model needs to undergo diagnostic evaluation before it can be used in process control strategy. This evaluation is conducted by plot the experimental data and predicted model on the same graph. The comparison between experimental data and predicted model was evaluated by coefficient of determination (R^2). Findings exhibited that the predicted process model gives good agreement with experiment data for all replications with R^2 is more than

0.9. It means that the model could explain about 90% of the total variability with the experimental data. The predicted model is accepted for process control because it was valid model with R^2 larger than 0.6 [15]. The ability of predicted model to represent dynamic behaviour of this process is interesting in order to use this model in control strategy.

Fig. 3 shows the correlation between experimental and predicted data of product temperature through linear relations. This correlation indicates the measurement of the relationship between the responses of experimental data and predicted model. A straight line in Figure 3 is the regression line that describes how a response of experimental data (y-axis) changes as a predicted value (x-axis) of model change. The linear relationship between these two data sets was estimated by correlation coefficient (*R*). The results showed that *R* values for all replications are 0.9579, 0.9516 and 0.9535, respectively. It means that relationship between these responses was good.

The parameters of model were estimated using three methods and listed in Table 1. From this table, all methods produce likely similar results in determination of model parameters. Therefore, any method can apply in model parameter estimation. Meanwhile, comparison between model parameters for all replications also exhibited quite similar value with small value of standard deviation (SD). A low value of standard deviation signifies small variability between model parameters for each replication, with values close to the average. Hence, the average values of model parameters were chosen to represent these models. In this study, average values from M3 were chosen due to their simple calculation [12]. These model parameters were replaced into (1) and (2) in order to get predicted model as presented in (3) and (4) for transfer function and time domain forms, respectively.

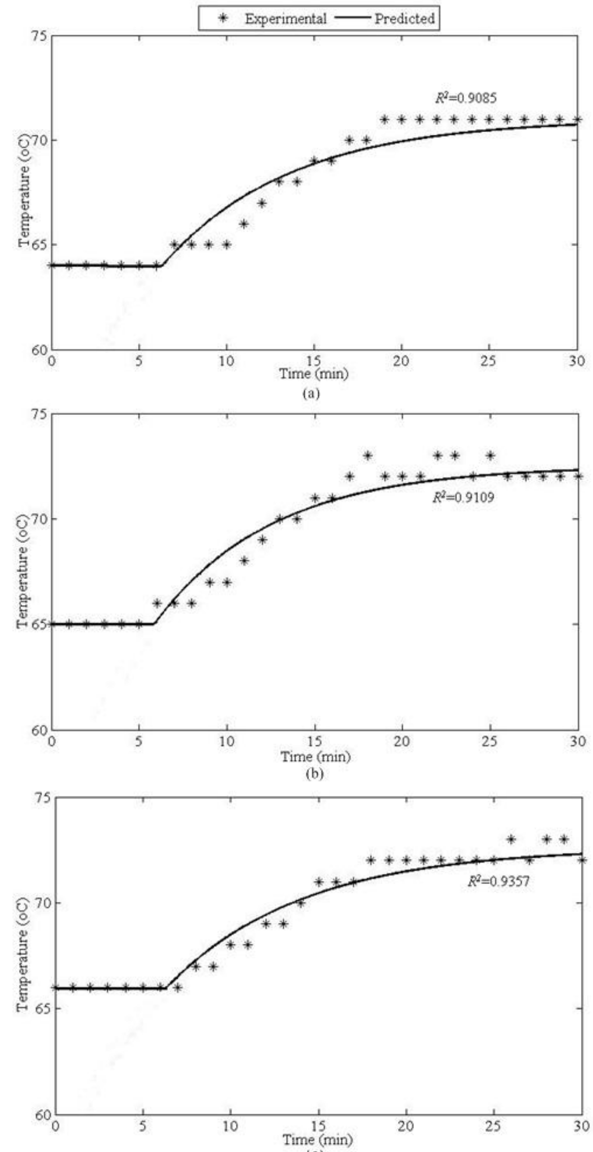

Fig. 2. Experimental data and predicted model for (a) E1; (b) E2; (c) E3

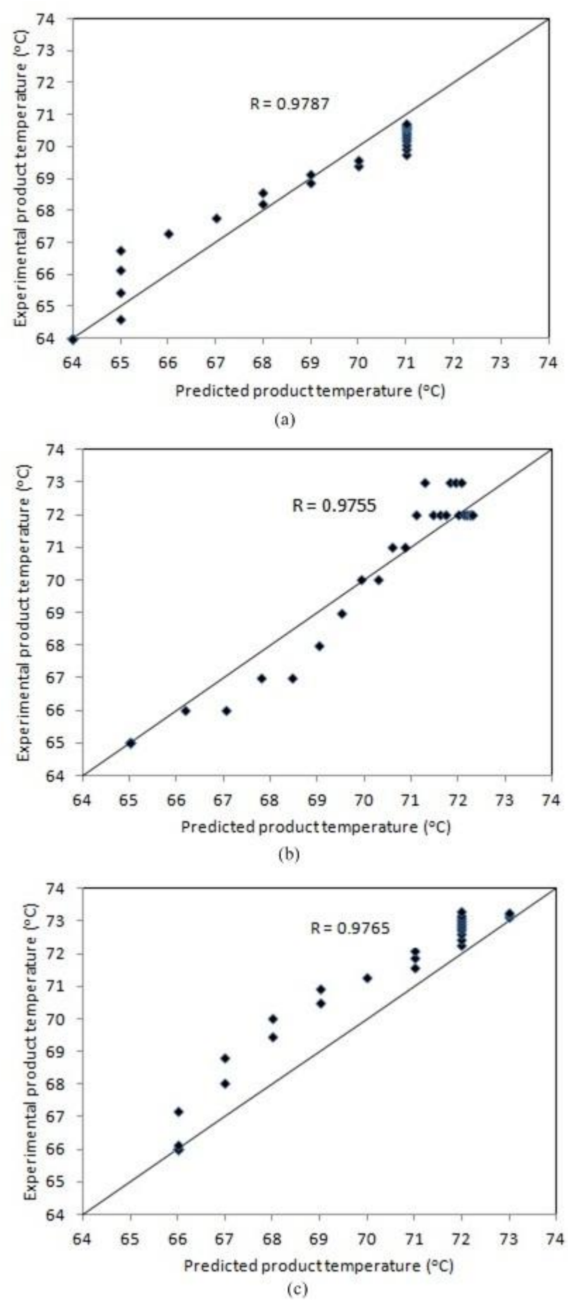

Fig. 3. Correlation of experimental data versus predicted data for (a) E1; (b) E2; (c) E3

Table 1. Estimated process parameters for all methods

	M1			M2			M3		
	K_p	θ	T	K_p	θ	τ	K_p	θ	τ
E1	0.70	1.34	7.29	0.70	1.25	7.11	0.70	1.30	7.29
E2	0.75	0.87	6.66	0.75	0.88	6.54	0.75	0.85	6.66
E3	0.66	1.36	7.69	0.66	1.33	7.58	0.66	1.36	7.65
Ave	0.70	1.19	7.21	0.70	1.15	7.08	0.70	1.17	7.20
SD	0.45	0.27	0.5	0.45	0.24	0.52	0.45	0.28	0.50

$$G(s) = \frac{0.7e^{-1.17s}}{7.2s+1} \quad (3)$$

$$g(t) = 7\left[1 - e^{-\left(\frac{t-1.17}{7.2}\right)}\right] + g(0) \quad (4)$$

3.2 Model Validation

Prior to used the obtain model in process control strategy, the predicted model must be validated. This validation process is a final stage and most important in model building sequence. The aim is to examine the capability of obtained models in predicting the dynamic response of product temperature. The obtained models have been validated by estimated maximum error bound with new set of experiment data. The maximum error bound is determined by plotted one set of experimental data versus predicted model as demonstrated in Fig. 4. This figure shows the obtained models give a good agreement with experimental data within ±5% of maximum error bound. Thus, it can be concluded that the obtained models are acceptable to use in control strategy for the next phase of study since the error less than 10% [16].

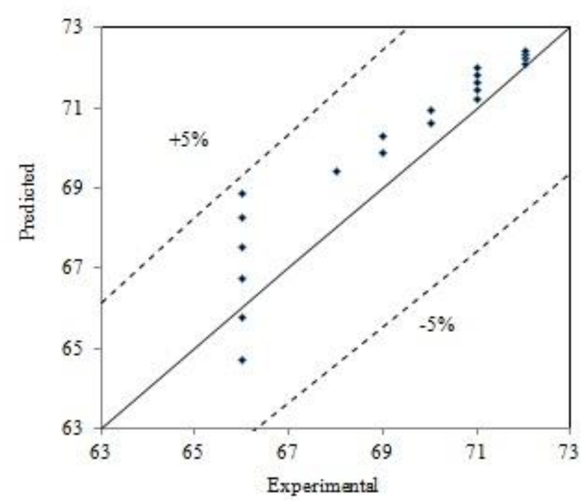

Fig. 4. Validation of predicted model

4. Conclusion

The process model of pasteurization process of coconut milk was successfully developed based on process reaction curve. The model was represented in first order plus time delay (FOPTD) model with R^2 more than 0.9. The predicted model was validated using new set of experimental data with maximum error is ±5%. This model will be used in the process control strategy in next stage of study.

5. Acknowledgement

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6. References

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