VOL. 11, NO. 15, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MODEL VALIDATION FOR TEMPERATURE PROFILE INSIDE FFB DURING STERILIZATION FOR PALM OIL MILL PROCESS

Arif bin Ab Hadi, Prof Dato' Ir. Abd. Wahab Mohammad and Prof Ir. Mohd Sobri Takriff
Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, National University of Malaysia, KM, Bangi Selangor, Malaysia
E-Mail: arifahadi85@gmail.com

ABSTRACT

The purpose of developing a reliable and accurate spreadsheet modeling tools was in order to investigate heat transfer efficiency inside mill sterilizer cage by predicting the temperature profile inside FFB at various locations inside the cage. The model was previously validated based on Mongana Report, Chan SY and Ang *et al* suggested that the model was best predicted by the experimental data which was taken from experimentally determined data of Ang *et al,* based on 15kg bunch at sterilization time of 1 hour (3600s) with the thermocouple inserted into a hole drilled near or beside stalk. In this study, an experiment was conducted to investigate the temperature profile inside FFB based on different FFB weights (12kg, 15kg and 18kg) by using temperature sensor probe inserted into a drilled hole beside FFB stalk and inside the stalk. The result suggest that temperature profile located at near or beside the stalk was best represented as the temperature profile located at the center of FFB as per validated result with Ang *et al*, with the smallest percentage error in the range of 0.31-5.82% for all FFB weight (12kg, 15kg and 18kg).

Keywords: model validation, temperature sensor probe, stalk, average FFB weight, percentage error

1. INTRODUCTION

The main purpose of having a mathematical modeling for single fresh fruit bunch is to predict the center temperature of FFB during sterilization process to indicate whether the fruit is sufficiently "cooked". The model is used as a practical approach to determine the adequacy of sterilization instead of having to insert the temperature sensor probe into the center of fresh fruit bunch every time. Besides that, it can also be used for analyzing the significance of changes in the operating conditions such as heating steam temperature, sterilization period, and different FFB weight and so on for optimization purposes during the process. In this study, the mathematical tool was used in order to estimate the optimum heat transfer rate inside sterilizer cage during sterilization process based on the temperature profile obtained inside FFB at various locations inside the cage.

An overview of previous work which was based on heat conduction spreadsheet model to predict time required for mesocarp to attain thermal equilibrium with the steam temperature (Mohd. Halim Shah. I, 2009). Another modeling study conducted using two theoretical bulk models developed for heat transfer model using computer software to investigate the temperature and time required for the center of fresh fruit bunch to become "cooked" (Chan SY, 1985). Based on the above, the spreadsheet mathematical model involving heat transfer was developed based on finite difference explicit method of heat transfer inside FFB (Frank, P., Incropera, David P. Dewitt, 2002) with several assumptions regarding the heat transfer coefficient, h and effective thermal conductivity value, k_{eff} (Arif bin Ab Hadi *et al.* 2015). The result was validated with the experimental and modeling data from Mongana Report (Mongana Report, 1955), Chan SY modeling data (Chan SY, 1985) and Ang *et al.* The temperature data obtained from Mongana report was based on 17kg bunch, triple peak sterilization and thermocouple inserted into FFB rachis (stalk) (Mongana Report, 1955) while the data taken from Chan SY and Ang et al was based on 15kg bunch with the thermocouple inserted into a hole drilled near or beside stalk (Chan SY, 1985). The result of validation shows that the calculated percentage error based on dT/dt between the predicted data by the model and experimental data from Ang et al is the closest, 0.48793%, followed by model results of Chan SY, 5.79256% and finally experimental data from Mongana Report, 18.14081%based on adjusted value of convective heat transfer coefficient, h set at 4250W/m^{2}K and effective thermal conductivity, k_{eff} at 8.7W/mK (Arif bin Ab Hadi *et al.* 2015).

However, the validation based on previous work was conducted at maximum sterilization time 1 hour based on the reported data for both Chan SY and Ang *et al* (Chan SY, 1985), and 50 minutes for Mongana Report (Mongana Report, 1955), which is much shorter duration as compared to the normal operating sterilization time at the mill of 80 minutes. In addition, the variation of temperature profile at different locations inside the FFB needs to be further verified in the laboratory in order to determine the result which is best represented as the temperature profile inside FFB to be used as an indicator for the optimum condition for satisfactory sterilization.

2. MATERIALS AND METHODS

In this study, the temperature profile inside FFB was determined based on two different locations, one located at near or beside stalk and another one inside the stalk. The experiment was conducted based on different FFB average weight of 12kg, 15kg and 18kg. The experiment consists of 5 trials for each FFB weight. The time of sterilization was set at 70 minutes excluding de-aeration period about 5 minutes during initial period. A laboratory scale experimental setup was conducted using a

VOL. 11, NO. 15, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

mini sterilizer from R and D Sime Darby Research Center, Klang.

During boiler start-up process, the steam inlet valve is closed. Once the pressure of boiler reaches the required value, the steam inlet valve is opened to allow steam to enter the sterilizer. The steam outlet valve is opened at both ends during boiler start-up process and de-aeration to allow steam purging. During pressure build up and cooking period, the outlet valve at right side (no bypass valve) is closed while the outlet valve at left side (with bypass valve) is opened to contain steam and opened again during exhaust. The function of the bypass valve which is to allow condensate purging during sterilization process hence is opened during the whole process. Figure-1 shows the schematic diagram of process flow for mini sterilizer for clarity.

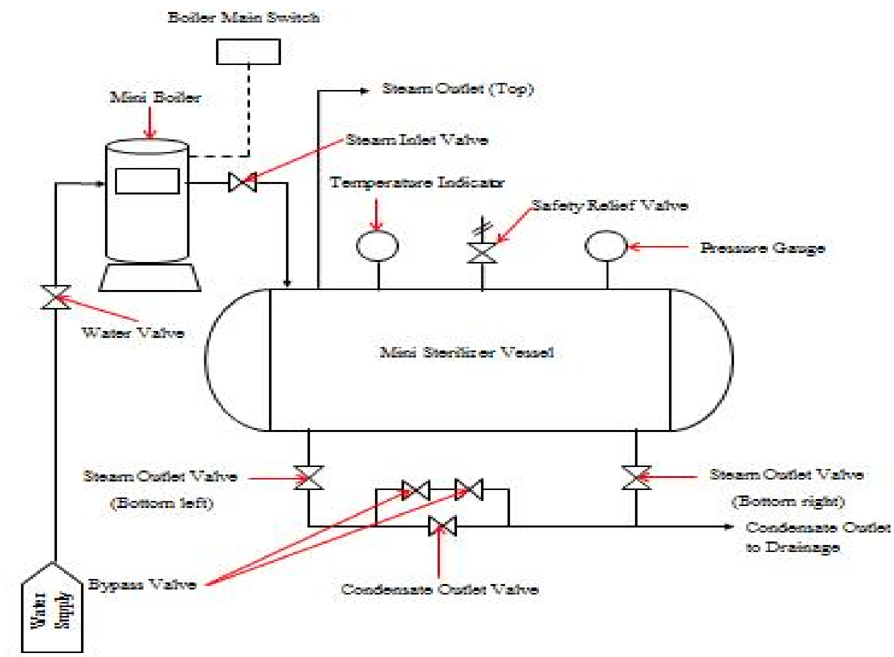


Figure-1. Schematic diagram of process flow for mini sterilizer.

The FFB sample is taken directly from the loading ramp of East Oil Mill as a sample for mini sterilization process. Note that the FFB samples were ripe in nature and taken at desirable weight at the loading ramp about 1 hour before being loaded into the mini sterilizer. The safety procedure for operating the mini sterilizer was carefully being conducted which includes the insertion of tray containing FFB, the opening and closing of sterilizer door, de-aeration, start-up and shutdown of the boiler, handling the steam inlet and exhaust before, during holding period and steam blowdown. The pressure was allowed to reach 2.5 bar g at saturation temperature of 140°C.

Before the FFB is inserted into the tray, temperature sensor device probe is inserted into the FFB by two methods, drilling a hole about 10 cm depth near or beside the stalk and another is by drilling a hole which penetrates through the center of the stalk. The tip probe with the length of about 12.1 cm inserted into the hole near or beside the FFB stalk is depicted by Figure-2(a) and Figure-2(b). A high temperature seal tape wrapped as per Figure-3around the tip of the probe to ensure no steam penetrated through the openings of the drilled hole. The experiment was repeated for 5 trials for each sterilization period, with one bunch per trial.

VOL. 11, NO. 15, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

(a) (b)

Figure-2. (a) Location of temperature probe tip inserted into hole drilled near or beside stalk (b) Location of temperature probe tip inserted into hole drilled inside stalk

Figure-3. High temperature-resistant seal tape.

(a) (b)

Figure-4. (a) Omega high temperature data logger sensor with thermal shield (b) Omega OM-CP-IFC400 software, USB cable and docking station.

Figure-4(a) and Figure-3(b) shows the high temperature data logger (OM-CP-HITEMP140-PT) from Omega Engineering used to obtain the temperature profile inside the mini sterilizer. The OM-CP-HITEMP140-PT is

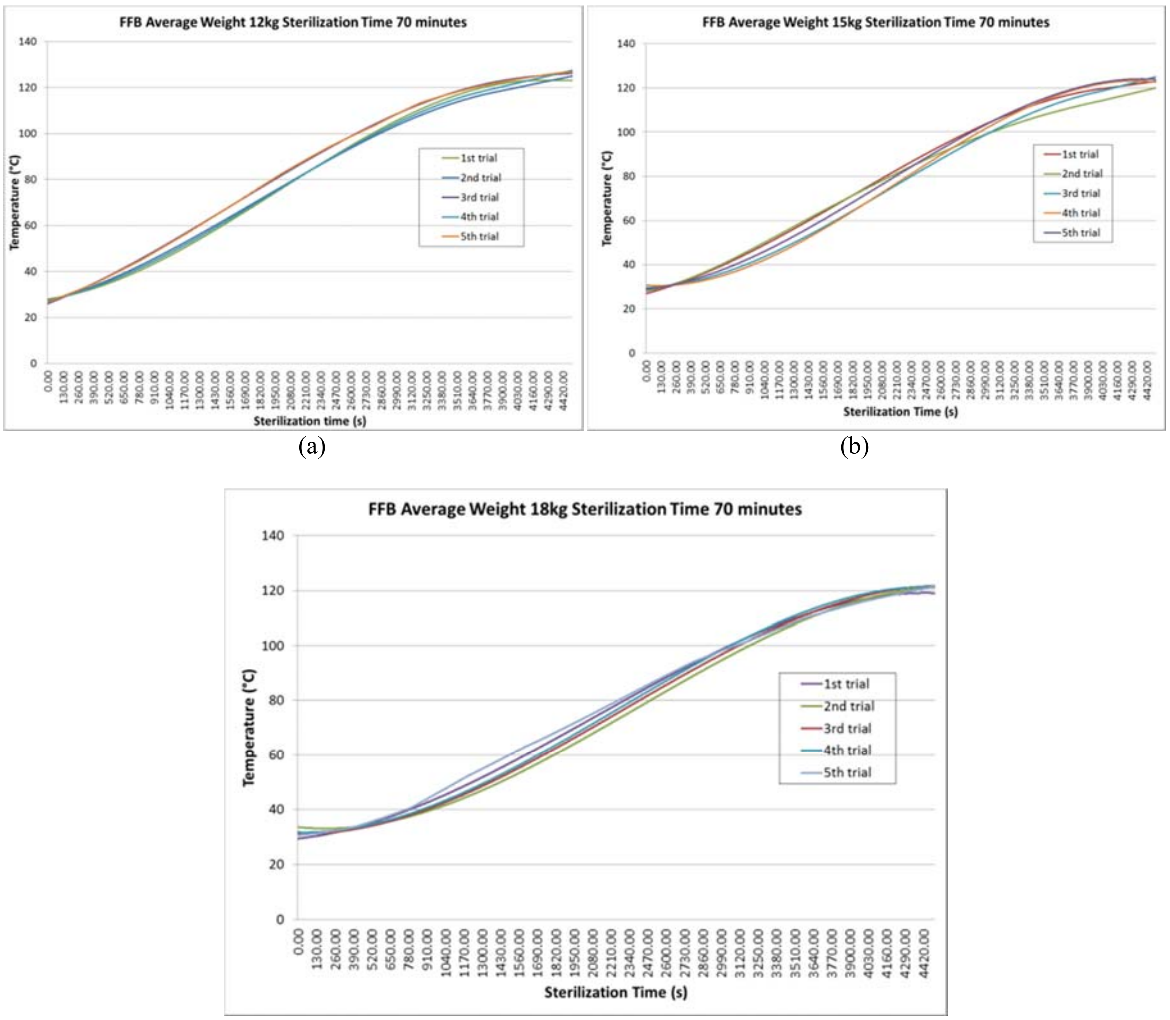
VOL. 11, NO. 15, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

submersible and can operate up to 140°C with an accuracy of ±0.1°C. This device features a 559mm flexible stainless steel probe and 121mm probe tip. The device comes with a thermal shield (optional during purchase) making it able to withstand up to 250°C. Using this device, the temperature profile inside sterilizer during sterilization process can be obtained for each trial.

3. RESULTS AND DISCUSSIONS

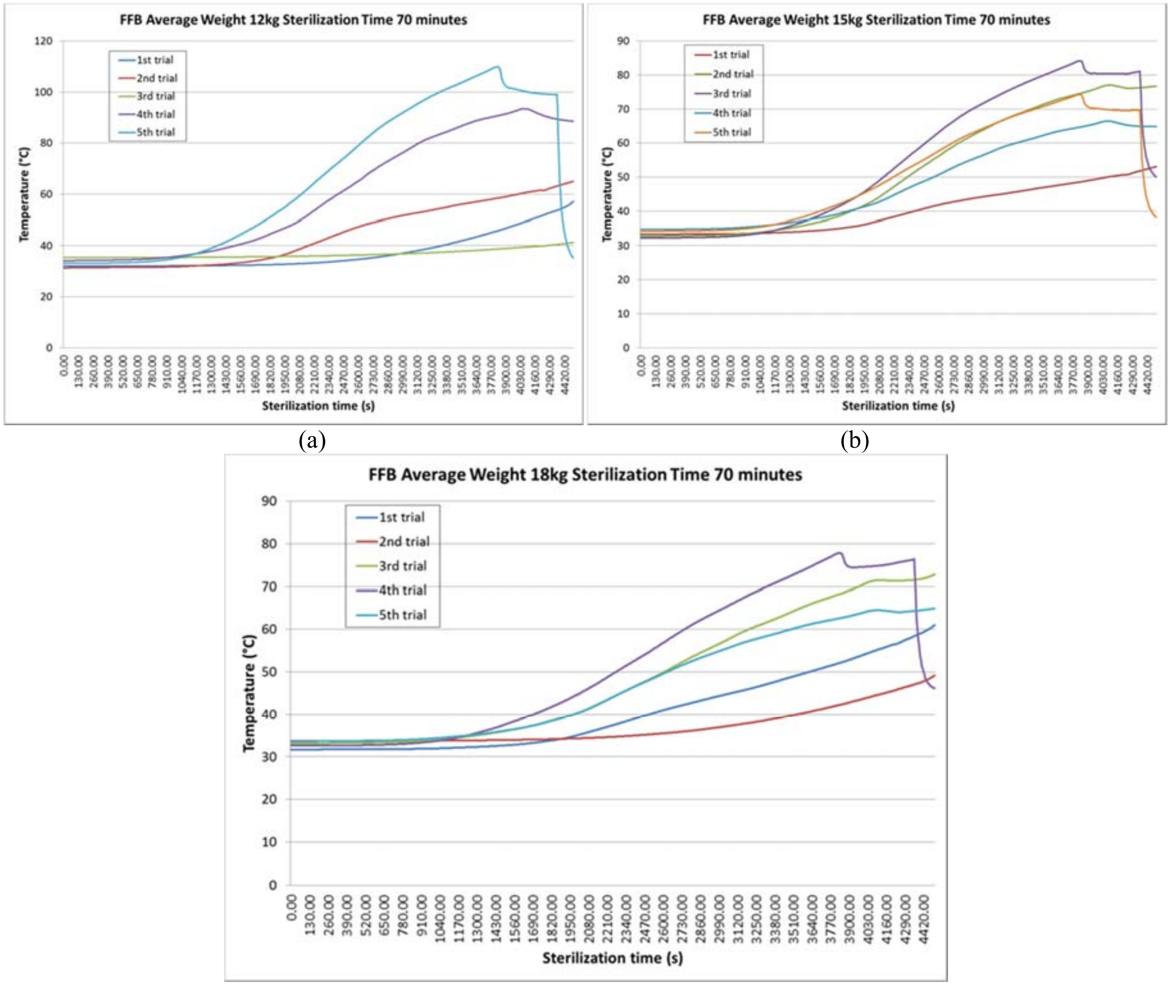
The result for temperature profile located at temperature probe inserted near or beside stalk for various FFB weight (12kg, 15kg, and 18kg) were shown as per Figure-5(a), Figure-5(b) and Figure-5(c), respectively. Also, the result for temperature profile located at temperature probe inserted into the center of stalk is shown as per Figure-6(a), Figure-6(b) and Figure-6(c).



(a) (b) (c)

Figure-5. (a) Temperature profile at near or beside FFB stalk (center) for 12kg (b) Temperature profile at near or beside FFB stalk (center) for 15kg(c) Temperature profile at near or beside FFB stalk (center) for 18kg.

VOL. 11, NO. 15, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences



(a) (b)

(c)

Figure-6. (a) Temperature profile at inside FFB stalk (center) for 12kg (b) Temperature profile at inside FFB stalk (center) for 15kg(c) Temperature profile at inside FFB stalk (center) for 18kg.

For model validation, the corresponding values of mesh size, Δx in the spreadsheet model were adjusted to the equivalent FFB weight used in this experiment. Table-1 list the corresponding value mesh sizes obtained based on the spreadsheet model after adjustment with respect to the equivalent FFB weight used. The calculated average dT/dt based on the given FFB weights was determined accordingly. The temperature difference per unit time, dT/dt and percentage error between experimental and adjusted model data was tabulated as per Table-2 and Table-3 (near or beside stalk) and Table-4 and Table-5 (inside stalk).

Table-1. Calculated dT/dt, FFB weight and corresponding mesh size based on adjusted model.

FFB average weight (kg)	**Mesh size** (m)	**dT/dt** (°C/s)
12	0.05697	0.02119
15	0.06137	0.02015
18	0.06521	0.01917

Table-2. Temperature difference per unit time for experimental data (near or beside stalk).

FFB average weight (kg)	**dT/dt** (°C/s)				
	1st trial	**2nd trial**	**3rd trial**	**4th trial**	**5th trial**
12	0.02112	0.02177	0.02225	0.02220	0.02228
15	0.02133	0.02042	0.02040	0.02119	0.02108
18	0.01988	0.01940	0.02007	0.01988	0.02024

ARPN Journal of Engineering and Applied Sciences

Table-3. Temperature difference per unit time for experimental data (inside stalk).

FFB average weight (kg)	**dT/dt** (°C/s)				
	1st trial	**2nd trial**	**3rd trial**	**4th trial**	**5th trial**
12	0.00553	0.00747	0.00132	0.01209	0.00054
15	0.00439	0.00977	0.00398	0.00670	0.00090
18	0.00652	0.00344	0.00882	0.00302	0.00696

Table-4. Percentage error between experimental data (near or beside stalk) and adjusted model.

FFB average weight (kg)	**Percentage error %**				
	1st trial	**2nd trial**	**3rd trial**	**4th trial**	**5th trial**
12	0.30805	2.75418	4.9973	4.80330	5.15805
15	5.81914	1.33774	1.24000	5.16422	4.60482
18	3.75299	1.24944	4.74287	3.75944	5.64924

Table-5. Percentage error between experimental data (inside stalk) and adjusted model.

FFB average weight (kg)	**Percentage error %**				
	1st trial	**2nd trial**	**3rd trial**	**4th trial**	**5th trial**
12	73.8942	64.7587	93.7908	42.9217	97.4513
15	78.1924	51.5056	80.2685	66.7710	95.5340
18	65.9947	82.0476	53.9840	84.2309	63.7092

Based on these data, it is observed that the smallest percentage error were obtained between the adjusted model data and temperature data taken near or beside stalk in the range of 0.31-5.82% for all FFB weight (12kg, 15kg and 18kg). A very high percentage error was obtained based on temperature data taken inside the stalk as compared to the adjusted model data, in the range of 51.5056-97.4513%. The significantly low value of dT/dt for inside FFB stalk suggests that the heat transfer occurs much less inside FFB stalk as compared to near or beside stalk. Moreover, the percentage also showed high fluctuations due to inconsistent steam penetration towards the inside FFB stalk, which is not suitable for data validation. In comparison, the fluctuations among the temperature data taken near or beside stalk is much smaller compared to inside stalk, therefore is more representable for data validation.

4. CONCLUSIONS

Based on the above, it is concluded that the result obtained for temperature data located near or beside stalk concurs with the adjusted model validated based on Ang et al experimental data with small percentage error in the range of 5%. Thus, the spreadsheet tool can be used together with data from temperature distribution inside sterilizer cage studies in order to determine the optimum condition for satisfactory sterilization.

ACKNOWLEDGEMENT

The author would like to thank the person in charge of R and D Sime Darby Research Center and Sime Darby East Oil Mill, Klang for providing research facilities and valuable assistance in conducting the study.

REFERENCES

[1] Arif bin Ab Hadi, Prof. Dato' Ir. Dr. Abd. Wahab Mohammad, Prof. Ir. Dr. MohdSobriTakriff. 2015. Spreadsheet Modelling for Temperature Profile inside Palm Oil Fresh Fruit Bunch. J. Ind. Eng. Res. 1(6): 25-32.

[2] Mongana Report, First Volume, 1955.

[3] Frank P., Incropera David P. Dewitt. 2002. Fundamentals of Heat and Mass Transfer, 5th edition. John Wiley and Sons

[4] Chan S.Y. 1985. Modeling and Simulation of the Sterilised of Fresh Oil Palm Fruit Bunches (FFB), University Malaya: Master Thesis.

[5] Mohd Halim Shah, I., A.A. Mustapa Kamal, M. Noor Azian. 2009. A system approach to Mathematical Modeling of Sterilization Process in Palm Oil Mill. European Journal of Scientific Research.