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NUMERICAL ANALYSIS OF SPRAY-DIC MODELING FOR FRUIT CONCENTRATION DRYING PROCESS INTO POWDER BASED ON COMPUTATIONAL FLUID DYNAMIC

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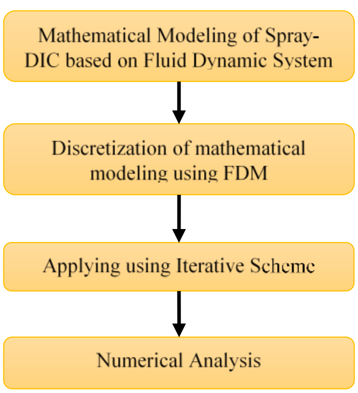
Graphical abstract



Abstract

The drying process is most popular preservation methods. It is important in producing the powder and natural dye by concentration fruit drying. Spray-DIC is one of the concentration techniques for drying process using the nozzle flow application in computational fluid dynamic. The mathematical modeling for drying process in this paper includes mass conservation and energy conservation of fruit concentration based on partial differential equation. The discretization of mathematical model will use the finite difference method with the initial and boundary conditions of nozzle flow application. The mathematical modeling computes numerical in sequential algorithm. Jacobi and Gauss-Seidel scheme will use to solve the linear system of mathematical modeling. The execution time, no of iteration, accuracy, root mean square error and maximum error are measured for investigating the numerical analysis. The results show the Gauss Seidel method is the alternative method compared to Jacobi method for solving the Spray-DIC modeling.

Keywords: Computational fluid dynamic; partial difference equation; numerical analysis; finite difference method

1.0 INTRODUCTION

Nowadays, food preservation is the technique to minimize the food waste problems in our country. Drying, pickling, canned and freezing food is examples of food preservation. However, food drying is most popular and widely use in our country [1]. Food drying can inhibit the growth of bacteria by removing the water vapor from the material surface into surrounding space [2]. Many types of food can be dried including fruits. The contribution in mathematical models in food dryer can give better quality, stability and functional as well as economic conditions throughout the country [3]. The production of fruits dehydration is not only dried the slice fruits dried, but it also can produce a fine and powder structure from fruit concentration. The applicable drying methods to produce powder structure in drying process are spray dryer, freeze dryer, spray-freeze dryer and others [4].

Mounir, Schuck [5] has developed the new technique for producing powder of skim milk production using spray-DIC dryer. This technique was more microbiological decontamination and low energy consumption rather than the others technique. This technique has motivated to this paper in investigating the mathematical model for drying process of powder using spray-DIC technique. The models are based on fluid dynamic system application which is the nozzle flow model in partial differential equation (PDE). The mathematical models are obtaining for predicting, observing and manipulating the changing in dependent and independent variables. These models important for conservation of mass and energy during drying process using spray-DIC dryer. There are several numerical methods to solving the PDE models. However, this paper is using Finite Difference Method (FDM) for discretization of the PDE models. The discretization of models is solved by Jacobi and Gauss-Seidel scheme in a linear system. The comparison of Jacobi and Gauss Seidel scheme will be analyzed based on time execution, accuracy, consistency, stability, root mean square error and maximum error. The sequential algorithm for these models will implement in C Programming Microsoft Visual software.

2.0 SPRAY-DIC DRIER

Spray-DIC drier was motivated from spray drier and DIC technique. It has developed from idea of high-air pressure (HAP-DIC) and low steam pressure (steam-DIC) in modification of skimmed milk powder powder [5]. Spray drier is commonly used in many sectors while DIC technique is the new technologies developed by Allaf et al. [6]. The present of DIC can control the interstitial air volume, porosity and compressibility on the dehydration process. The schematic of the spray-DIC dryer can be illustrated as Figure 1:

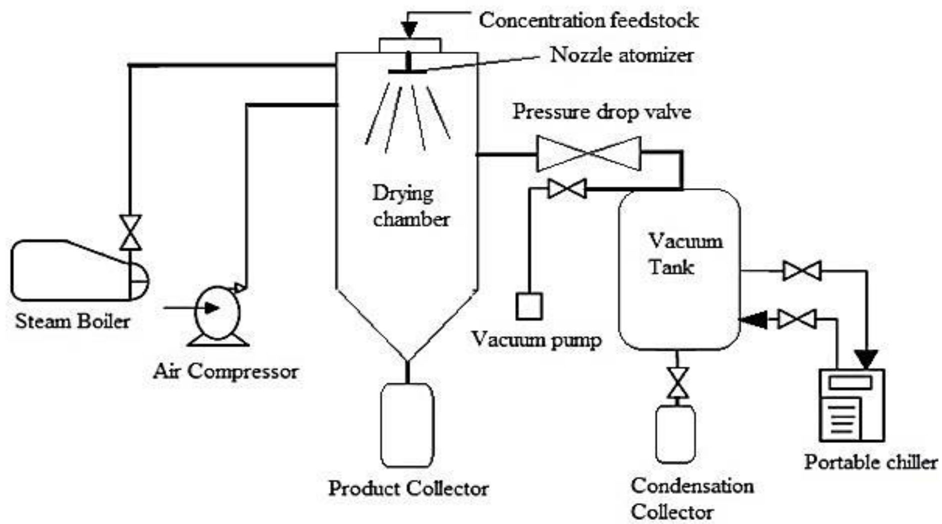


Figure 1 Schematic presentation of spray-DIC dryer

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The spray-DIC dryer has a few operational stages. The first stage is the concentration of food is textured by nozzle spray dried in first drying to swell them and reformed their volume and pore content. This stage will increase the fixed surface area of granules and produce the compact wet granules. In order to produce the highest quality of the powder, commonly the fixed area must be higher than 200m2/kg [7]. The next process is a treatment of DIC dried operative parameters. In this process, the molecule of H2O inside the fruit granule is broken with high pressure. The higher the DIC steam pressure, the higher the expansion rate. The last process drying is carried out in an independent drier with a stream of dry air at 50°C. Then, the powder sample is ready for characterization. The stages of spray-DIC can be summarized as Figure 2 follows:

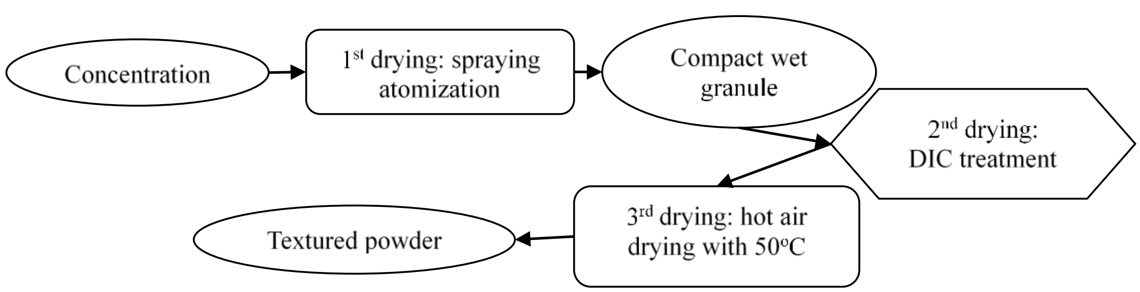

Figure 2 Process of spray-DIC technique

During the process, there are four main transport types of moisture and heat transfer [8]:

i) Internal heat transfer transmits the energy by heat conduction condition
ii) External heat transfer carries out energy based on contact, convection or radiation process
iii) Internal moisture mass transfer transports the water content in liquid and vapor phase
iv) External mass transfer process

3.0 MATHEMATICAL MODELING

Using of fluid dynamic system in spray-DIC drier because the present of nozzle atomizer in first stage of process. Murtaza [9] and Mezhericher, Levy [10] has been study the spray drying modeling based on fluid dynamic system involved mass, momentum and energy conservation. The governing of mathematical modeling based on nozzle flow in fluid dynamic system in quasi one-dimensional PDE form to predict the water removal from the samples and temperature behavior. The assumption of governing the model is:

i) Temperature of product remained constant and equal to the air temperature during the drying process
ii) Uniform initial moisture and temperature distribution
iii) External resistance to the mass transfer was negligible
iv) Negligible radiation effects

The mass and energy conservation models for spray-DIC are given by:

$$\frac{\partial \rho}{\partial t} + \rho_w \frac{\partial u_j}{\partial x_j} = S_c + \frac{\partial P}{\partial x_j}, \qquad (1)$$

$$\rho_w \frac{\partial T}{\partial t} + \rho_w u_c \frac{\partial T}{\partial x_j} = k \frac{\partial^2 T}{\partial {x_j}^2} + \frac{\partial P}{\partial x_j} + \rho C_p \,. \qquad (2)$$

4.0 DISCRETIZATION

This paper focuses on Finite Difference Method for discretization of mass and energy conservation models for spray-DIC technique. By dimensionalize and neglecting the truncation error, the finite difference approximation equations (1) and (2) can be simplified as

$$\rho_j^{(t+1)} = \rho_j^{(t)} - \rho_w \lambda_1 u_{j+1}^{(t)} + \rho_w \lambda_1 u_{j-1}^{(t)} + a_0 \lambda_1 P_{j+1}^{(t)} - a_0 \lambda_1 P_{j-1}^{(t)} + \Delta t \alpha \,, \qquad (3)$$

$$T_j^{(t+1)} = (1 - 2\lambda_2 \beta_1) T_j^{(t)} + (\lambda_2 \beta_1 - \lambda_2 \beta_2) T_{j+1}^{(t)} + (\lambda_2 \beta_1 + \lambda_2 \beta_2) T_{j-1}^{t} + \lambda_2 \beta_3 P_{j+1}^{(t)} - \lambda_2 \beta_3 P_{j-1}^{(t)} - \beta_4. \qquad (4)$$

The parameters in these models as shown in Table 1 below:

Table 1 Parameters for mass and heat equation.

$\lambda_1 = \frac{\Delta t}{2\Delta x}$	ρ	density of sample
$\lambda_2 = \frac{\Delta t}{2(\Delta x)^2}$	T	Temperature
$\alpha = \frac{L S_c}{\rho_0 a_0}$	P	Pressure drop
$\beta_1 = \frac{2k{a_0}^2}{\rho_w T_0}$	u_j	velocity of concentration in j-direction of chamber
$\beta_2 = u_c \Delta x$	Δt	time step for time
$\beta_3 = \frac{a_0 \Delta x}{\rho_w T_0}$	Δx	time step for x-direction
$\beta_4 = \frac{2\Delta t \rho_0 a_0 L^4 C_p}{{T_0}^2}$	x_j	j-direction in chamber
$S_c = \frac{\upsilon}{D}$	t	time
	L	Length of chamber
	ρ_0	Initial density
	a_0	Speed of sound
	T_0	Initial temperature
	ρ_w	Density of water
	u_c	Initial velocity
	C_p	Specific heat
	υ	Viscosity of concentration
	k	Thermal conductivity
	D	Molecular mass of concentration

4.0 NUMERICAL SCHEME AND SEQUENTIAL ALGORITHM

The discretization of the models in equation (3) and (4) will be linearized in a linear system. The numerical schemes that focus on this paper are used Jacobi and Gauss-Seidel scheme.

4.1 Jacobi Scheme (JB)

Jacobi method or JB scheme is a one of the essential iterative methods in solving FDM. JB method computes the value of u for each component. The following equation is the JB method:

$$u_i^{(k+1)} = \left(b_i - \sum a_{ij} u_j^{(k)}\right) / a_{ii}, \quad i = 1,2,3, \dots, m$$

The scheme is repeated until it reaches the stopping criterion, $\left|u_i^{(k+1)} - u_i^{(k)}\right| \leq \varepsilon$ where ε is the convergence criterion.

4.2 Gauss-Seidel Scheme (GS)

GS is an improved version of the JB method. The calculation of this method is as follows

$$u_i^{(k+1)} = \left(b_i - \sum_{j>i} a_{ij} u_j^{(k)} - \sum_{j<i} a_{ij} u_j^{(k+1)}\right) \Big/ a_{ii}, \quad i = 1,2,3,\dots,m$$

The scheme is repeated until it reaches the stopping criterion such that $\left|u_i^{(k+1)} - u_i^{(k)}\right| \leq \varepsilon$ where ε is the convergence criterion.

The computation of the models refers to the sequential algorithm in Figure 3 as follows:

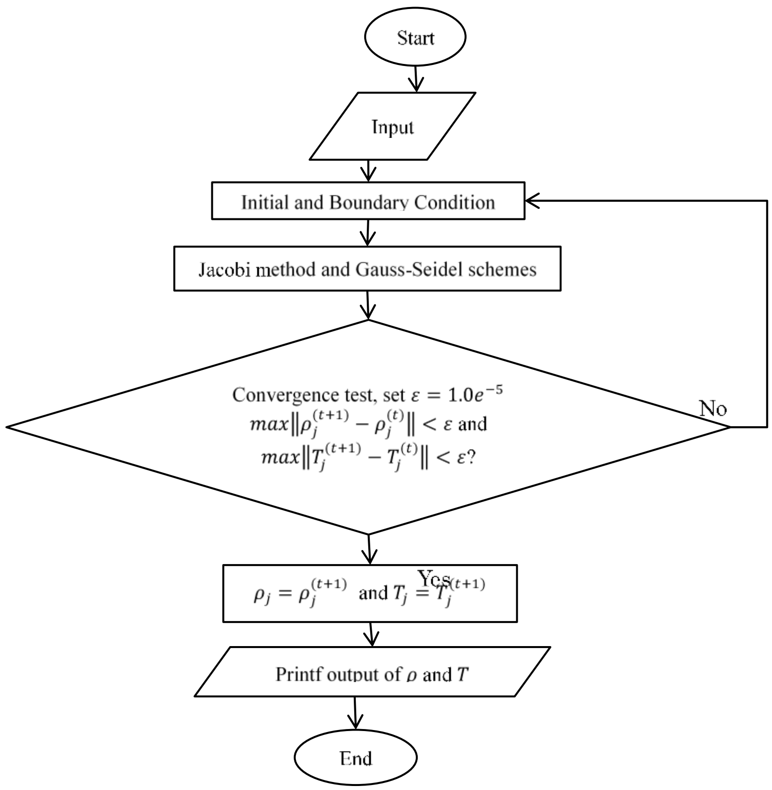

Figure 3 Sequential algorithm of mass and energy conservation

5.0 RESULT AND DISCUSSION

The software for computational this model is using C programming while for visualize the graph is using Microsoft Excel. The software is running on platform Intel CORE i3 and Windows 8 as the Operating System. The Figures 4a and 4b below show that the mass and energy conservation for spray-DIC technique:

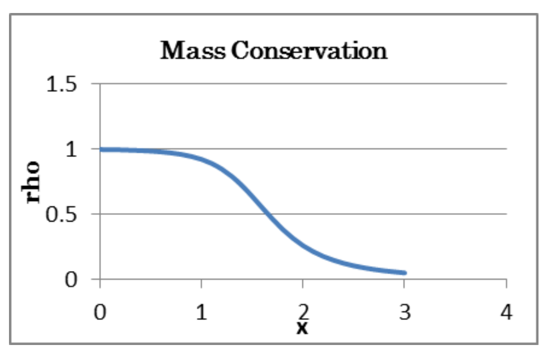

Figure 4a Visualization of mass conservation (Equation 1)

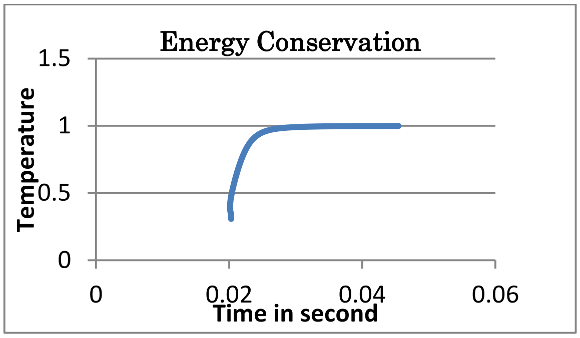

Figure 4b Visualization of energy conservation (Equation 1)

From the graph above, mass and energy conservation can depended on pressure drop in DIC-technique. Figure 4a shows that the mass of concentration is decreasing with respect to x-axis of the chamber. Figure 4b shows the temperature inside the concentration is increasing with respect to time(s). The mathematical models are solved using Jacobi and Gauss Seidel schemes. Table 2 shows the numerical analysis based on the execution time, number of iterations, maximum error, and root mean square error (RMSE) for every numerical scheme.

Table 2 Comparison between jacobi with gauss-seidel scheme.

Equation	Method	Execution Time (s)	No. of Iteration	Maximum Error	RMSE
Mass	JB	0.792	102	4.05127e-003	1.300152e-001
	GS	0.706	80	3.88652e-003	1.299716e-001
Energy	JB	0.832	122	1.061224e-002	1.300049e-001
	GS	0.821	110	0.961224e-002	8.934512e-002

From the result in Table 2, it is shown that Gauss-Seidel is a superior method compared to Jacobi scheme. The computation using Gauss-Seidel involves faster time and high accuracy with the smallest value of maximum and root means square error for both models. The value of parameters used to solve the mass and energy conservation equation as given by:

Table 3 Parameters for numerical solve of the models

Parameters	Symbols	Value
Interval	Δx , Δt	0.01, 0.001
Lamda	λ	0.05
Tolerance	ε	10^{-9}

6.0 CONCLUSION

This paper presents the mathematical modeling for drying process involves the mass conservation and energy conservation of fruit concentration based on partial differential equation in fluid dynamic. This paper also presents the visualization and simulation the drying process using a spray-DIC technique. Finite difference method (FDM) has been used in this paper to discretize the models. The computational of models is in sequential algorithm. From the result, this paper has proved that Gauss Seidel scheme is superior method compared to Jacobi scheme based on the time execution, number of iteration, maximum error, root mean square error and accuracy. For the future study is to implement the parallel algorithm for these models with large sparse problem.

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