Mathematical model analysis of fluid flow in edamame hydrofluidization using finite element method

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Abstract. Edamame, also called as vegetable soybean is a major agricultural commodity export in international scale. The market demand for edamame has begun to increase for recent decades. Therefore, it was necessary to pay attention to its freezing process in order to produce frozen edamame with worldwide superior quality. One of the freezing processes called Hydrofluidization. It uses the circulation system by pumping the coolant upward through the orifice plate into the cooling vessel. This research was intended to examine the mathematical model of fluid flow on edamame hydrofluidization. This mathematical model was solved using finite element method with quadratic approach and simulated with MATLAB and FLUENT software. The problem of the research to be examined was the initial fluid velocity and the diameter of the orifice plate. It was found that the bigger of the orifice plate, the lower of the fluid velocity in edamame hydrofluidization was. However, the higher of the initial fluid velocity that given, the higher of the fluid velocity in edamame hydrofluidization was. Based on the result of MATLAB simulation, with the size of the diameter of orifice plate about 0.01 m, the fluid velocity is decreased to 0.5019 m/s. While at the diameter of orifice plate about 0.02 m and 0.03 m is decreased to 0.6347 m/s and 0.6593 m/s.

1. Introduction
Edamame is called a vegetable soybean that has many health benefits. Edamame is healthy because it does not contain cholesterol and saturated fat [1]. Edamame is a substance known that can release the immune system. In addition, edamame also contains isoflavones which can reduce the risk of prostate cancer and breast cancer. Edamame is a plant that easily planted and harvested. Edamame was harvested when the pods were young and green (when filling 80-90% of the seeds) [2]. Edamame is an export commodity that needs attention in the producing process to produce frozen edamame with superior quality in accordance with foreign standards. One of freezing technique that can be applied in edamame freezing is hydrofluidization. Hydrofluidization is a food freezing technique that uses a circulatory system by pumping liquid into a cooling vessel [3]. Edamame hydrofluidization takes place in an experimental tank with a vessel and there is a hole in the bottom of the vessel.

Based on a relevant research conducted by Liang and Li [4] with the title "Simulation of Heat Transfer in Hollow-Glass-Bead-Filled Polypropylene Composites by Finite Element Method", it showed that temperature changes more quickly inside the sphere than outside the sphere. Furthermore, a research conducted by Orona, Susana, and Juan [5] entitled "Computational Fluid Dynamics Combined With Discrete Element Method and Discrete Phase Models For Studying A Food Hydrofluidization System" about heat transfer in potato hydrofluidization systems with a simulation of Computational Fluid Dynamics (CFD) and Discrete Element Method (DEM), stated that CFD and
DEM can simulate food processing systems, where a certain amount of small or large food particles move within the fluid domain, with minimum computational requirements compared to approaches where fluid to particle interactions with moving meshes are used.

This study modifies the mathematical models of Orona, Susana, and Juan. The mathematical model is solved using the finite element method with a quadratic approach. The process of analyzing and simulating mathematical models using MATLAB and FLUENT software. The main objective in this study was to determine the mathematical model of fluid flow in edamame hydrofluidization, to determine the effect of the initial fluid velocity and diameter of the orifices plate to the fluid velocity in edamame hydrofluidization by using finite element method. Therefore, determine the effectiveness of finite element method in analyzing fluid velocity in edamame hydrofluidization is based on the error obtained.

The mathematical model is a representation of the real system which is spelled out in the form of symbols and mathematical statements [6]. The basic equation of the fluid model in edamame hydrofluidization uses the momentum equation, i.e.: 
\[
\frac{\partial \rho \phi_0}{\partial t} + \frac{\partial \rho \phi_y}{\partial y} = F_p v + \frac{(\rho_p - \rho)}{\rho_p} g + F_{DEM}
\]
with \( \rho = \) density (0.98x10³), \( \rho_p = \) density of edamame (0.78x10³), \( v = \) velocity of y axis, \( g = \) gravity (9.8), \( F_p = \) tensile force per unit of edamame balls, and \( F_{DEM} = \) force per units of edamame balls due to interactions between edamame balls [6]. The momentum equation is formed based on the law of conservation of momentum which is derived through the differential equations of fluid motion by observing the volume of terms or system of elements. Furthermore, the equation will be solved using the finite element method with a quadratic approach. The finite element method is one of the numerical approaches that bases the problem on each part element called finite element [7]. By using finite element method can simulate edamame hydrofluidization process, where a certain amount of small or large food particles move within the fluid domain, with minimum computational requirements compared to approaches where fluid to particle interactions with moving meshes are used.

2. Research Method

Finite element method is one of approach method of numeric that bases on the problems at every part of element that is named by finite element [8]. Finite element method is kind of numeric approach method which is based on the problem of each element called finite element [9]. Therefore, finite element method is a numeric approach method used to solve continuum mechanics problems. The method employed in this research is simulation. The procedure in this study is doing literature review in term of the fluid velocity on edamame hydrofluidization, then making the fluid velocity of edamame hydrofluidization model, then examining the fluid velocity in edamame hydrofluidization.

3. Result and Discussion

This study aims to develop a mathematical model of fluid flow in edamame hydrofluidization. The study of mathematical model of fluid flow in edamame hydrofluidization is an equation which is expressed in momentum equation. Then, the equation would be finished by finite element method with quadratic approach and simulated by MATLAB and FLUENT software.

Figure 1 shows that, the fluid velocity in edamame hydrofluidization which is influenced by the diameter size of the orifices plate. In this simulation, the diameter size of the orifices plates of 0.01 m, 0.015 m, 0.02 m, 0.025 m, and 0.03 m with an initial fluid velocity of 1.25 m/s. The fluid velocity in edamame hydrofluidization with a diameter of the orifices plate about 0.01 m is 0.5019 m/s. Whereas at the diameter of the orifices plate about 0.015 m, 0.02 m, 0.025 m, and 0.03 m the fluid velocity increased respectively about 0.6003 m/s, 0.6347 m/s, 0.6505 m/s, and 0.6593 m/s. The graph shows that there is a difference in the fluid velocity based on the different size of the orifices plate diameter. The larger size of the orifices plate diameter, the smaller the fluid flow in edamame hydrofluidization.
Figure 1. The graph of the fluid velocity which is influenced by diameter of the orifices plate.

Figure 2 shows that, the fluid velocity in edamame hydrofluidization which is influenced by the initial fluid velocity. In this simulation, the initial fluid velocity about 1 m/s, 1.125 m/s, 1.25 m/s, 1.375 m/s, and 1.5 m/s with a orifices plate diameter about 0.01 m. The fluid velocity in the edamame hydrofluidization with the initial fluid velocity about 1 m/s decreased to 0.4294 m/s. Whereas at the initial fluid velocity about 1.125 m/s, 1.25 m/s, 1.375 m/s, and 1.5 m/s then the fluid velocity increases respectively about 0.5598 m/s, 0.6789 m/s, 0.7868 m/s, and 0.8835 m/s. The graph shows that there is a difference in the fluid velocity due to the five initial fluid velocity that are different, the greater the initial fluid velocity given, the greater fluid velocity in edamame hydrofluidization.

Figure 2. The graph of the fluid velocity which is influenced by the initial fluid velocity.

The results of FLUENT simulation will present the figure of simulation from fluid velocity in edamame hydrofluidization. The model that will be simulated with FLUENT previously will be
designed used GAMBIT program with various size of the orifices plate diameter. The results of FLUENT simulation in the form of 2D (2 Dimension) simulations. These various diameter of the orifices was selected due to its ability to express significant increasing fluid velocity which recorded by MATLAB.

The first simulation of fluid velocity in edamame hydrofluidization which is influenced by diameter of the orifices plate. Based on Figure 3, it showed that the fluid velocity in edamame hydrofluidization with diameter of the orifices plate of 0.01 m has the smallest fluid velocity. We can see the dominant color which is blue in fluid velocity on the top of vessel and a combination green-yellow on the edge of the vessel wall. Figure 4 shows that the fluid velocity with diameter of the orifices plate of 0.01 m was faster than the fluid velocity with diameter of the orifices plate of 0.01 m. In this case, we can see the dominant color which is light blue-green on the top of vessel and a combination of green-yellow on the edge of the vessel wall dominant. Figure 5 shows that fluid velocity in edamame hydrofluidization with diameter of the orifices plate of 0.03 m was the highest velocity. In this case, we can see through the green dominant color on the top of vessel and the green-yellow dominant color on the edge of the vessel wall.

Figure 3. Fluid velocity with diameter of the orifices plate of 0.01 m.

Figure 4. Fluid velocity with diameter of the orifices plate of 0.02 m.

Figure 5. Fluid velocity with diameter of the orifices plate of 0.03 m.

The second simulation is the simulation of the fluid velocity which is affected by the orifices plate diameter. Based on Figure 6, it showed that the fluid velocity in edamame hydrofluidization with the initial fluid velocity of 1 m/s has the smallest fluid velocity. We can see the blue color on the top of the vessel and a combination of green and yellow on the edge of the vessel wall. Figure 7 shows that the fluid velocity in edamame hydrofluidization with the initial fluid velocity is 1.25 m/s was faster than edamame hydrofluidization with the initial fluid velocity about 1 m/s. This can be seen from the blue color on the top of the vessel turn into yellow and green color, then a combination of green and yellow on the edge of the vessel wall is increasingly dominant. Figure 8 shows that the fluid velocity in
edamame hydrofluidization with the initial fluid velocity of 1.5 m/s which is the highest fluid velocity. This is indicated by the blue-green colors on the top of the vessel and the combination of yellow-greenon the edge of the vessel wall. The fluid velocity in the section of the vessel plate tends to be high. This is indicated by the red color of the orifices plate, but at the initial fluid velocity about 1.5 m/s has the highest fluid velocity than the other initial fluid velocity.

Figure 6. Fluid velocity with the initial fluid velocity of 1 m/s.

Figure 7. Fluid velocity with the initial fluid velocity of 1.25 m/s.

Figure 8. Fluid velocity with the initial fluid velocity of 1.5 m/s.

Based on this research, the mathematical model of fluid flow in edamame hydrofluidization is an effective model to solving the influence of the diameter size of the orifices plate and the initial fluid velocity. It can be seen from the very small error from the calculation of MATLAB. Based on the calculation of MATLAB using the Gauss-Seidel method, the relative error is 0.0038326 with a tolerance limit of 0.01.

4. Conclusion and Suggestion
Based on the study about the fluid velocity in edamame hydrofluidization which is influenced by the diameter of the orifices plate, we conclude that the larger size of the orifices plate diameter and the smaller of the initial fluid velocity, the faster of the fluid velocity was. The fluid velocity with the initial fluid velocity about 1.125 m/s, 1.25 m/s, 1.375 m/s, and 1.5 m/s decrease respectively about 0.4294 m/s, 0.5598 m/s, 0.6789 m/s, 0.7868 m/s, and 0.8835 m/s. The greater of the initial fluid velocity given, the greater fluid velocity in edamame hydrofluidization was. Then the fluid velocity in edamame hydrofluidization with the size of the orifices plate diameter is 0.01 m, 0.015 m, 0.02 m, 0.025 m, and 0.03 m is respectively 0.5019 m/s, 0.6003 m/s, 0.6347 m/s, 0.6505 m/s, and 0.6593 m/s. The greater size of the orifices plate diameter given, the smaller the fluid velocity in the edamame hydrofluidization was.
Based on the results of research about the fluid flow in edamame hydrofluidization, the researcher may give suggestion about improving the study result by using real geometrically figure based of the vessel in edamame hydrofluidization. In the future, the authors will extend this work by conducting research based on the analysis of other factors that influence the edamame hydrofluidization process.

Acknowledgement
We would like to thank to University of Jember, Jember, Indonesia, which offer grants and an opportunity to disseminate the intellectual output of our research.

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