Numerical analysis of ice freezing processes of block ice production in a brine tank factory using the finite volume method

A Fatahillah1,*, T B Setiawan1, and A Sholihin1
1Department of Mathematics Education, University of Jember, Jember, Indonesia
E-mail: arif.fkip@unej.ac.id

Abstract. Brine Tank is a tank that serves to freeze ice blocks. Brine Tank contained salt water to condense water. Numerical analysis and simulation were carried out after a mathematical model of the ice freezing process in the Brine Tank space was formed. The simulations used in this study were Matlab and Fluent. The matlab graphic result of ice freezing process in brine tank factory ice box with an initial temperature 301 K faster than initial temperatures of 302 K and 303 K. Results graph using freezing MATLAB with a pool temperature 266 K faster than an temperature of 267 K and 268 K. Based on the MATLAB calculation results using the Gauss Seidel iteration method and the exact calculation, it show that the results of the difference between the numerical temperature value of each node and the exact temperature value of each node is less than 0.001

1. Introduction
Computational fluid dynamics is a mathematical science that is often used in industry, for example in the ice making industry. Ice is frozen water. Shape changes occur when water is cooled below 273 K at standard atmospheric pressure. Fishermen use ice blocks to maintain the quality of the fish so that it looks fresh. Tube ice which has a hollow cylinder in shape with about ¼ inch in diameter and 1 inch long is normally [1]. The main activity of the ice block production process is the process of ice freezing in the Brine Tank.

Brine Tank is a tank of ice freezing which serves to place ice mold media. Brine Tank is contained of salt water serves as a refrigerant to take heat from the water so that the water freezes. According to Sukborom (2017) the freezing process occurs optimally using a pool temperature of 263 K [2]. Based on Michalek's (2003) research that the freezing process is influenced by several internal factors in the refrigerator [3]. Factory conditions need to be considered in order to achieve the optimal freezing process. Each ice factory has a different optimal pool temperature.

The freezing process is influenced by raw material of water in producing ice and pool conditions. Based on the influence of the ice freezing process, the mathematical model is produced from two equations, namely the momentum equation and the energy equation.

\[
\frac{\partial \rho \phi_0}{\partial t} + \nabla \rho u_i u_i = \mu \nabla u + F_f \quad \ldots \ldots (1)
\]

\[
\frac{\partial \phi_0}{\partial t} + \nabla u_i u_i = k \Delta T - \rho \frac{\partial \alpha_i}{\partial t} \quad \ldots \ldots (2)
\]

With

\[F_f = \sigma \frac{\rho \gamma \nabla \alpha_i}{1},\]

\[Q = \alpha \rho c_p T + \alpha_i \rho_{i} c_{pi} T_i\]
\( \rho \) is a density of water, \( \alpha \) is the dynamic viscosity of water, \( c_p \) is a fixed heat of water, \( \rho_i \) is a density of salt liquid, \( \alpha_i \) is a dynamic viscosity of a salt liquid, \( c_{p_i} \) is a salt liquid heat, \( T \) is water temperature and \( T_i \) is pool temperature.

Based on the explanation above, this research aimed to form and develop mathematical models in the ice freezing process in the Brine Tank. Mathematical models were solved using the finite volume method and QUICK discretization. The mathematical model was simulated with the parameters of the initial temperature effect, and the effect of the pool temperature on the MATLAB program used the Gauss Seidel and geometrically simulated the ice freezing process in the Brine Tank room using the FLUENT.

2. Methods

Mathematical modelling is a branch of mathematical field, can represent and explain the physical systems or the problem in the real life into mathematical expression [4]. The research method is the stage carried out to get the data to be analyzed to arrive at conclusions that are consistent with the research objectives. The method employed in this research is simulation [5]. Simulation research is a replication or visualization of the behaviour of a system. Simulation is a model that contains a set of variables that display the main characteristics of real life systems.

The first step that must be done in this research is collecting data and supporting the theory in order to get to design [6] model the process of ice freezing in the brine tank space of the block ice factory used the volume method so that results or data that are close to the actual state are obtained. Then made the algorithm in MATLAB as well as made geometric designs of the ice freezing process in the brine tank space using Gambit. The next step is to simulate the algorithm program in MATLAB and simulate geometric designs on FLUENT. The solidification/melting model [7] which based on enthalpy-porosity technique in the FLUENT program was used. The water properties for the solidification study follow [8]. The final step in this research was analysing and drawing conclusions from the simulation results.

3. Results and Discussion

Numerical analysis on the ice freezing processes in brine tank began with forming a mathematical model. Mathematical models were used to describe fluid flow in freezing processes in brine tank. Mathematical models were composed of momentum equations and energy equations. After determining the mathematical model, the next step is to determine the appropriate discretization method or differential approach with the object of research. The numerical results were obtained from the discretization method of differential equations with a system of algebraic equations that can be solved by computer using MATLAB.

The numerical approach method for freezing processes in Brine Tank uses the finite volume method. The finite volume method used the integral form of the general equation to discretize the equation. The ice cubes are partitioned into several finite volume controls and a general equation that had been discretized wa applied to each volume control. Furthermore, the algorithm was compiled in the MATLAB program so that a numerical approach solution can be obtained using the discretization method of differential equations with a system of algebraic equations that can be solved by computer.

In addition to analyzing the numerical results of the mathematical model simulation in the MATLAB program, this article also analyzes the ice bookkeeping process by simulating geometric design in the FLUENT program. Based on the results of observations and study of journals, we obtained variable data that affect the ice freezing process. The table 1 shown the data variable obtained from the results of journal studies and field observations at the ice factory:
Using the Gauss Seidel iteration method, the simulation results are presented in graphs and tables. The first case is the effect of the initial temperature on the ice block freezing process. Initial temperature used was 301 K, 302 K and 303 K. Soaking time was 10 hours with a pool temperature of 266 K and the tolerance limit used was 0.001.

After deepening within 10 hours the temperature in each node is obtained in Figure 1. The graph in blue shows the temperature of the ice block with water temperature of 301 K. The graph in red shows the temperature of the block ice at water temperature of 302 K. While the graph in green shows the temperature of the block of ice with the initial temperature of water of 303 K.

Table 2 makes it easy to read the graph in Figure 1. In Table 2, shows that the initial temperature of 301 K produces ice temperatures cooler than the initial temperature of 302 K and 303 K. Based on the graph and the resulting ice produced in Table 2, it can be concluded that the freezing process is getting quickly if the initial temperature of the ice water is lowered first.
Table 2. Effect of Initial Temperature

| Coldest temperature produced | 301 K | 302 K | 303 K |
|-----------------------------|-------|-------|-------|
| Numerical Value             | 266.2112 | 266.2715 | 266.3319 |
| Exact Value                 | 266.2109 | 266.2717 | 266.3321 |

The second case is the effect of pool temperature on the ice block freezing process. The pool temperature was 268 K, 267 K, and 266 K. Soaking time was 10 hours with an initial temperature of 303 K and the tolerance limit used is 0.001.

In Figure 2, the graph in blue shows the ice temperature with a pool temperature of 266 K. The graph in red shows the ice temperature with a pool temperature of 267 K. While the graph in green shows the ice temperature with a pool temperature of 268 K.

Table 3 shows the acquisition of ice cold temperatures in the graph in Figure 2. In Table 3 shows that the pool temperature of 266 K produce ice temperatures cooler than the pool temperature 266 and pool temperature 266. Based on the graph in Figure 5 and the results of ice produced in Table 3 then it can be concluded that the freezing process is faster when the brine temperature used is lower but also adjusted to the concentration of salt.

Figure 2. Effect of Pool Temperature Charts

Table 3. Effect of Pool Temperature

| Value | Coldest temperature produced | 266 K | 267 K | 268 K |
|-------|-----------------------------|-------|-------|-------|
| Numerical Value |                             | 266.3319 | 267.4965 | 268.4729 |
| Exact Value      |                             | 266.3321 | 267.4963 | 268.4732 |

Furthermore, the simulation of the ice raw material in the freezing process initial temperature effect with FLUENT application. Figure 3 is the result of a fluent simulation with an initial temperature of 301 K. Figure 4 is the results of a simulation with an initial temperature of 302 K and Figure 5 is the
results of a simulation with an initial temperature of 303 K. The difference in contours can be seen from the three figures, in Figure 3 the resulting ice temperature is cooler than Figure 4 and figure 5. The higher the initial temperature the longer the freezing process.

Figure 3. Simulation Initial Temperature 301

Figure 4. Simulation Initial Temperature 302 K
Furthermore, the simulation of the effect of pool temperature on the freezing process with FLUENT.

**Figure 5.** Simulation Initial Temperature 303 K

**Figure 6.** Simulation Pool Temperature 268 K

**Figure 7.** Simulation Pool Temperature 267 K
Figure 6 is the result of a fluent simulation with a pool temperature of 268 K, Figure 7 is the result of a simulation with a pool temperature of 267 K, and Figure 8 is the result of a simulation with a pool temperature of 266 K. From the three pictures, it can be seen that the blue color contour is different. In figure 8, the contour is increasingly visible, meaning that the resulting ice temperature is cooler than Figure 6 and Figure 7. Previous theoretical research shows that the lower the pool temperature, the faster the freezing process [1]. This was proven by the results of matlab and FLUENT simulation in this study, the colder the temperature of the pool used the faster the ice freezing process.

The effectiveness of the finite volume method in completing the ice block freezing process in the Brine Tank room is analyzed based on the calculation error level obtained. Error is the difference between numeric value and exact value. Exact calculation is obtained by forming the temperature of each node which is a dependent variable that will be searched into matrix form. The mathematical model obtained is a form of linear equation with the variable T. The value of T can be determined by the matrix equation $P X = R$. With $P$ a matrix consisting of coefficients of the variable T, matrix $X$ is a matrix consisting of variables T, whereas matrix $R$ is a matrix consisting of constants

The matrix is obtained in the equation $P X = R$. Through computing the MATLAB program, the value of the matrix $X$ can be found by means of $X = P^{-1} R$. Based on the MATLAB calculation results using the Gauss Seidel iteration method and the exact calculation results in table 2, table 3 and table 4 the difference between the numerical value of each node and the exact value of each node is less than 0.001.

4. Conclusions

Based on the discussion, the mathematical model of the process of ice freezing in the Brine Tank space is an equation that states the momentum equation and the energy equation and the smooth matlab simulation results show the greater the initial temperature, the faster the freezing process. It can be seen in graph 1 the results of simulations with initial temperatures of 301 K, 302 K, and 303 K produce the coldest temperatures, respectively 266.2112 K, 266.2715 K, and 266.3319 K. The results of the Matlab and Fluent simulation show that the smaller pool temperature will be the freezing process will be faster and faster. This can be seen in the graph 2 simulation results with a temperature of 266 K, 267 K, and 268 K producing the coldest temperatures 266.3319 K, 267.4965 K, and 268.4729 K. The results of the Matlab and Fluent simulation show a greater salt concentration in the freezing process were getting closer.
faster and faster. The finite volume method is an effective method for analyzing the ice freezing process in the Brine Tank chamber because the calculation error obtained is less than 0.001.

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