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Airflow Distribution Analysis of Reefer Container with Skipjack Tuna Load using Computational Fluid Dynamics

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ABSTRACT

In the transportation of skipjack tuna to various destination countries, it is crucial to ensure that the skipjack tuna persists and remains of high quality. This study aims to analyse the airflow distribution inside the reefer container with the cargo load of skipjack tuna. The analysis carries out the computational fluid dynamics method to obtain appropriate airflow settings and investigate the temperature distribution inside reefer containers. The designed reefer container is 40ft with detailed structural variables of the T-bar and flat floor. The simulation result shows reefer containers that use the T-bar floor provide offer a thorough airflow distribution to cooling pallet stacks with full load conditions. The finding of the simulation results is the airflow rate of 5 m/s and the inlet temperature of -6°C will provide optimal cooling distribution.

1. Introduction

Tuna and skipjack are types of fishery resources that are used for local consumption and export commodities, with the second largest export value after shrimp [1]. Based on data from the Indonesian Central Statistics Agency, exports of tuna and skipjack in March 2020 were recorded at USD 176.63 million [2]. However, fish is a highly perishable commodity. Fresh fish spoils faster than meat, so that this decay will greatly affect the protein content of the fish [3].

In the process of distributing fish using ships, there is a reefer container to accommodate pre-cooling, storage, handling at the distribution center to the landing site [4]. The process of distributing air evenly in the reefer container is particularly important to ensure even cooling of the fish in the reefer container [5]. The heat source in the cooling process inside the reefer container comes from the fan motor, heat infiltration or heat infiltration from outside, and solar radiation [6]. If the temperature inside the reefer container cannot be controlled properly, it can be ascertained that there will be an increase in hot air [7]. Environmental factors will affect the energy consumption of a refrigerator [8, 9]. The increase in outdoor temperature and heat source from solar radiation will

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increase power consumption [10, 11]. Several studies have been conducted to improve energy efficiency in open refrigerators during the day [12, 13]. In addition, chilling injury / hotspot due to non-uniform cooling causes loss of quality in fish in the reefer container [14].

Therefore, controlling the air temperature in the reefer container is particularly important to maintain the quality of skipjack tuna and reduce losses. However, to control the temperature in the reefer container, there are several factors, including external climatic conditions, insulation, thermal reefers, product respiration rate, and the air circulation cycle of the reefer container design, packaging design and arrangement of packaging arrangement in the reefer container [15]. When using experimental methods to deal with these factors, it is certain that it will take long time experiments. Thus, using the Computational Fluid Dynamics (CFD) method is the main method of choice to visualize the spatial, temporal resolution of airflow, and temperature distribution with an acceptable level of accuracy [16].

In the application of the CFD method on reefer containers [17, 18], there are several aspects that need to be considered, one of which is the placement of the skipjack tuna which is formed in packages on pallets. Another thing that needs to be considered is the area inside the pallet fish packaging to the wall requires a perfect arrangement, this aims to avoid cells or tilted arrangements. Thus, the actual geometry of the arrangement will be made into a porous medium housing. In this case, skipjack tuna will be stacked which is simplified into a medium consisting of a solid phase and a fluid phase with a constant volume fraction in time and space. Using this approach has the benefit of managing computing power requirements so that it can complete airflow and heat transfer in the characteristics of reefer containers that will later be packaged. For the porous domain, a model of thermal equilibrium between the solid phase and the fluid phase will be achieved for each corner of the reefer container having the same solid temperature as the fluid temperature. Thus, using a zonal porous approach can delineate the area within the refrigeration facility. Then, positioning and stacking pallets will affect the distribution of airflow [19].

In accordance with the explanation contained in the background, the problem that will be brought up in this research is how the application of CFD in the design of the reefer container model can provide stable cooling results by taking into account temperature factors, time differences, external factors, namely ambient temperature, solar radiation, flow velocity varying air quality, application of porous media on skipjack tuna packaging. Then, the results obtained from the simulation model on CFD can later be compared with experimental measurement data and simulations that have been carried out on the Reefer Container under full load conditions.

This study aims to analyze the airflow distribution inside the reefer container with the cargo load is skipjack tuna. The analyze using the CFD simulation method to obtain optimum airflow results in reefer containers and the distribution value to be applied to reefer containers. The scope of the research is setting the CFD model on the reefer container by considering the nature of production, operational parameters, and solid packaging design parameters. study the effect of various operational parameters on the reefer container. The contribution of the results of this final project is to provide knowledge related to model design with CFD simulation on reefer containers that are effective when designing or implementing the model.

2. Methodology

The research conducted in this simulation uses the Computational Fluid Dynamics (CFD) method using Fluent [20]. The CFD simulation can analyze the air flow conditions and air temperature inside the reefer container to produce the right setting values for the temperature and air velocity. Figure 1 describes the work process of this research. The reefer container used in the simulation model has a total length of 12.2 meters, a total width of 2.4 meters, and a total height of 2.8 meters. Meanwhile, the interior is 11.5 meters long, 2.2 meters wide and 2.5 meters high. The geometry of the reefer container used as the case in the simulation is shown in Figure 2.

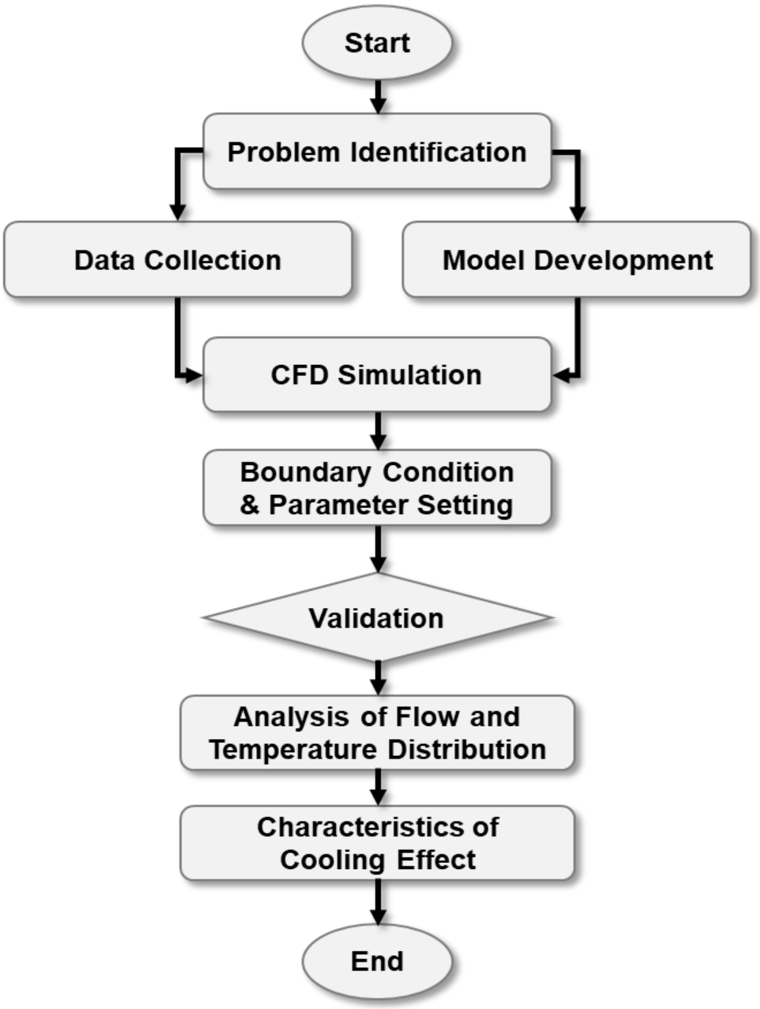

Fig. 1. Flowchart diagram of CFD simulation of reefer container

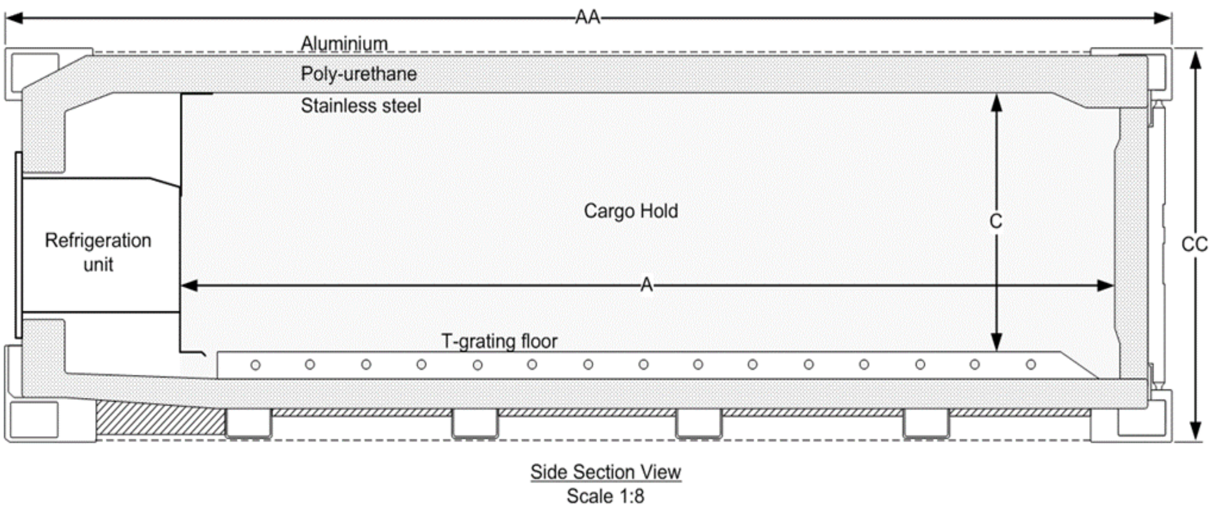

Fig. 2. The geometry of reefer container for the simulation model

For the outer layer of the reefer container made of aluminum, it is intended as a barrier layer of water vapor from the outside air into the reefer container. The insulation layer has a polyurethane base material, aiming to prevent heat from entering from the outside or the leakage of cold air from the inside. Cooling in the reefer container, the air passes through the bottom of the reefer and the air returns to the reefer at the top of the cooling unit.

Boundary conditions and initial parameter settings are shown in Figure 3 and Table 1. The model contains a fluid domain bounded by a model containing a fluid domain bounded by reefer walls, doors, ceilings, floors, inlet air inlet plates and cooling unit side walls. The fluid domain inlet in the calculation is determined from the speed and temperature values measured at the exit from the evaporator fan.

Table 1
Initial parameter setting of simulation model

Boundary condition	Inlet	Outlet
Velocity, v (m/s)	10 m/s	-
	5 m/s	
Turbulence intensity (I_t)	8.56%	3.87%
	3.86%	3.87%
Temperature	271.65 K	282 K

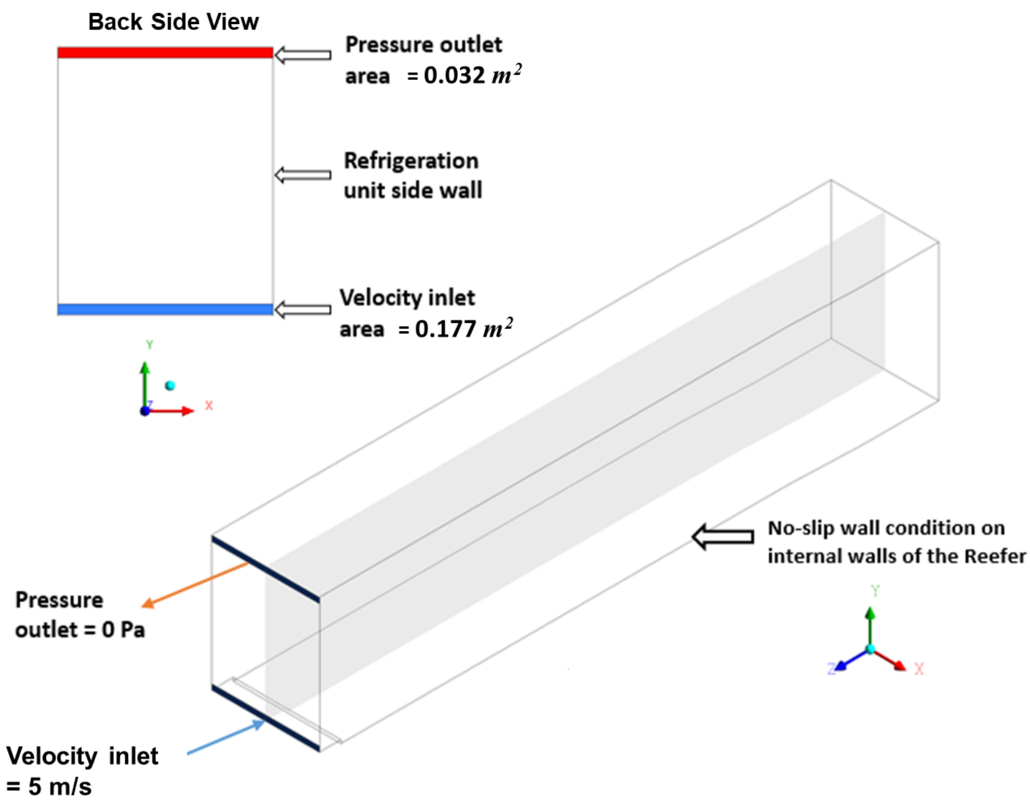

Fig. 3. Boundary conditions and initial parameter settings

For the temperature applied to 0°C, when the ship sails, the temperature will rise and fall according to the conditions of the sun outside. However, the required temperature for skipjack tuna is 3-5°C so that the initial temperature is 3.8°C and maintains that temperature. Initial parameter setting is shown in table 1. In the simulation process, the reefer container is carried out with flat and T-bar designs. In addition, the validated model is used to evaluate the speed with its variation of 10 m/s and 5 m/s, then evaluate the temperature with its variation of 0°C, -3°C, -6°C of the evaporator fan in the floor design model T- bar and flat floor.

3. Results and Discussion

In the simulation process, the reefer container is carried out with flat and T-bar designs. In addition, the validated model is used to evaluate the speed with its variation of 10 m/s and 5 m/s, then evaluate the temperature with its variation of 0°C, -3°C, -6°C of the evaporator fan in the floor design model T - bar and flat floor. This discussion is different from the previous research, where the simulation process time was up to 7 hours, previously it was only 40 minutes. Then the temperature of the outside air temperature fluctuates, previously it was fixed at 18 °C. The results of the simulation will get a graph of the air velocity against the height of the reefer container with varying distances. Measurements taken refer to variations in height differences, namely 1, 4, 8, and 11 m axially (along the X axis) from the inlet side to the door side.

Figure 4 shows the air velocity in the simulation. Figure 4a is at 1 meter near the inlet region, the airflow is more likely to stick to the floor. This is because the air moves horizontally. It is evident from the inlet air inlet which is under the cooling unit. Thus, the air flow velocity is more dominant and larger on the reefer container floor. Figure 4b is at 4 meters from the inlet side, the air velocity at the top is significant. As can be seen from the figure pattern from 4 m to 8 m along the z-axis, the airflow pattern is almost the same i.e., higher near the floor, lower in the middle and higher in the upper area. Figure 4c is 8 meters from the inlet side, the air velocity at the top is significant along the z-axis, the airflow pattern is almost the same, namely higher in the upper area and lower to the floor area. Figure 4d is at 11 meters, the highest air flow velocity is at the top.

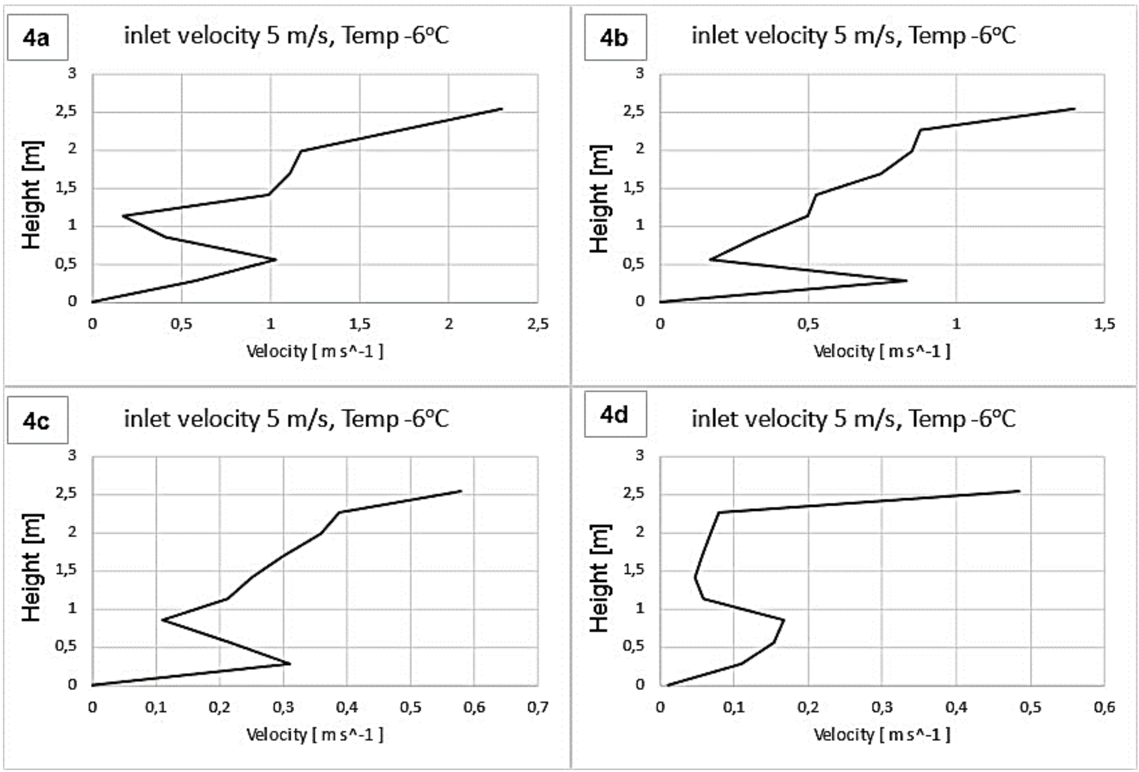

Fig. 4. Variation of inlet speed of flat floor reefer container during empty condition

Different things when the conditions in the reefer container already have pallets and their cargo, a simulation is carried out on the air flow velocity plot on a flat floor reefer model containing fish pallets. Figure 5 shows the inlet velocity profile of a reefer container with a flat floor at full load. From the two graphs that have been collected from when it was empty and when it was filled the pallet could be seen quite significantly. Because the velocity of the air flow generated in the reefer container containing fish pallets is higher in the middle. This is because, the design of the formation of the reefer container model is described as having 2 rows of fish pallet stacks. Which is where the stack of fish pallets that have been arranged has a gap or barrier between the two rows. Thus, the air flow velocity in the center is more likely to be greater than near the floor or at the top of the reefer container ceiling.

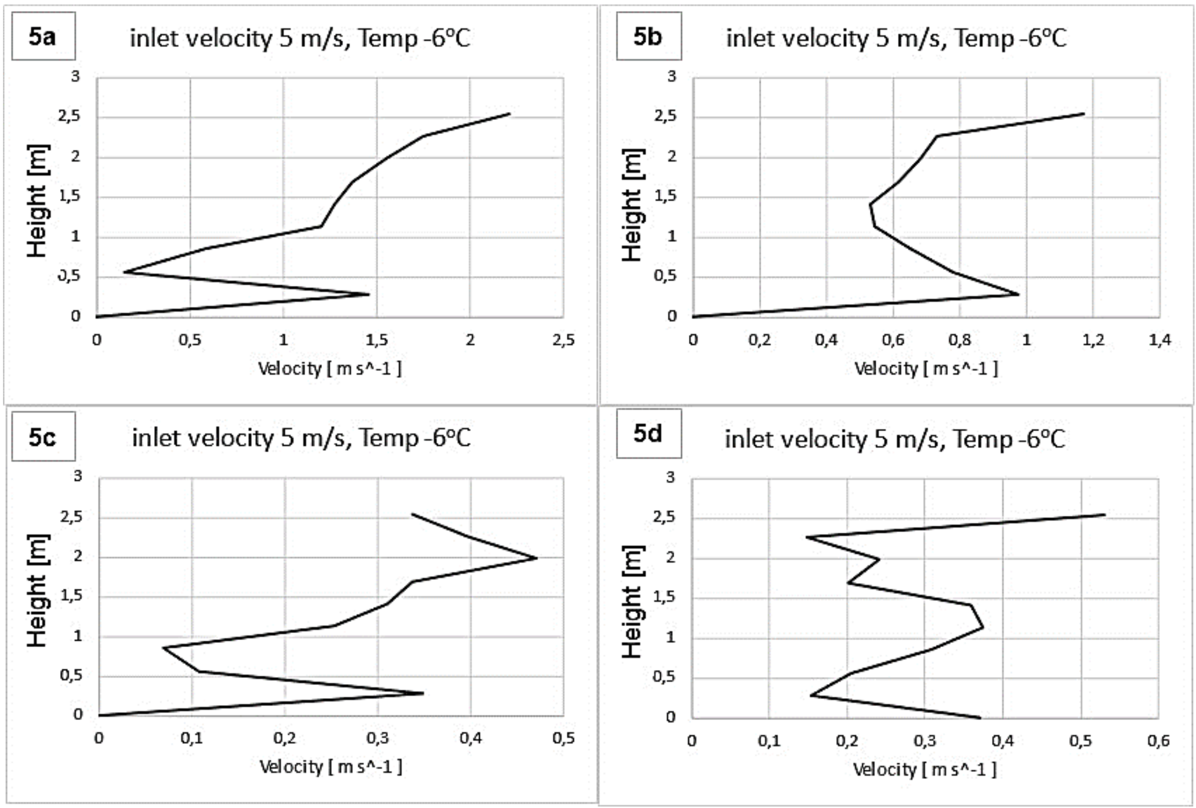

Fig. 5. Inlet velocity profile of a reefer container with a flat floor at full load condition

Figure 6 shows the inlet velocity profile on a reefer container with a T-bar floor at full load. Graphic data given that the air velocity from the inlet is 5 m/s and the set temperature is -6 degrees with a given load in it, it can be seen from the graph that the highest air velocity value is the one approaching the roof of the reefer container. This is because the movement of air is hampered from the arrangement of the skipjack cargo on the pallet.

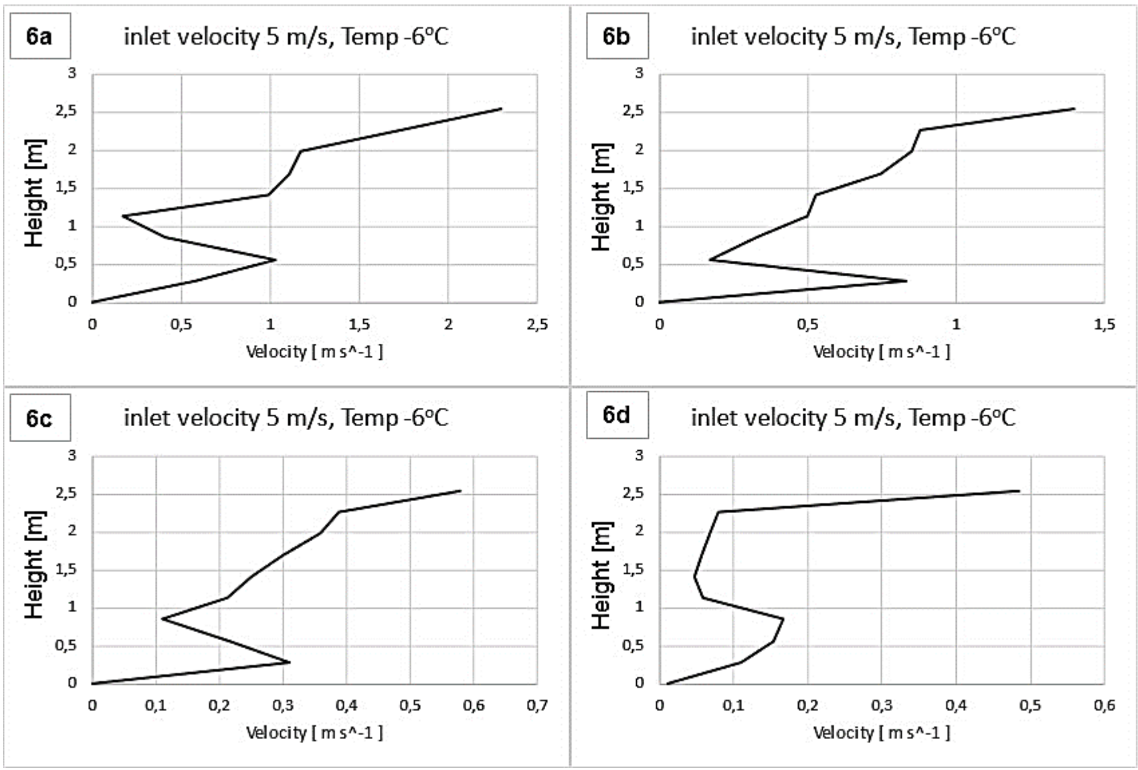

Fig. 6. Inlet velocity profile of a reefer container with a T-bar floor at full load condition

Figure 7 shows the temperature distribution of a Reefer container using a T-bar floor with skipjack tuna loaded on a pallet. The temperature distribution at 60 minutes is presented. From the contours that have been presented, all parts of the reefer container both on the ceiling, refrigeration unit, walls, door, and floor have different temperature ranges. From the four contour images above, the ceiling area or the top of the reefer container has a high temperature. This is because the area has the same direction at the airflow exit at the outlet hole whose position is above the inlet hole. The second reason is that the sun is shining at the top so there is a radiation factor given.

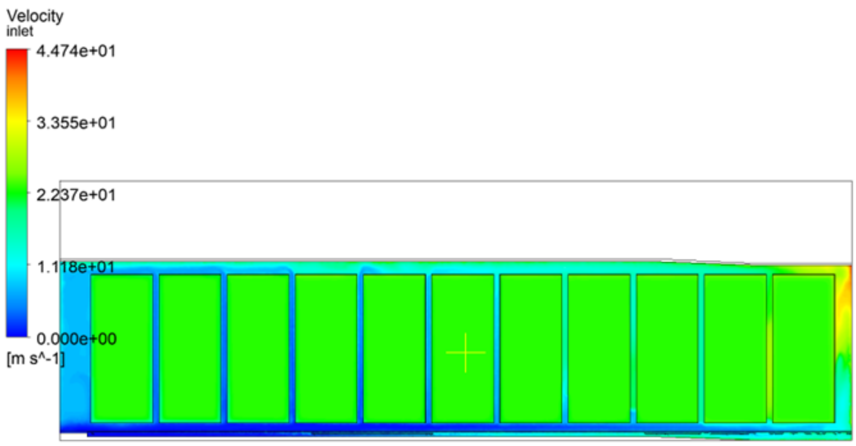

Fig. 7. Temperature distribution at 60 minutes at full load condition

The inlet's air moves from the bottom to the top. For the part of the fish load that is above the pallet, the temperature is stable. However, the temperature inside the load changes slightly, especially in the ceiling near the door. This is because the airflow is far from the inlet and passes through many piles of cargo on the pallet. In addition, there is the influence of heat generated from the respiration process of fish and solar radiation over time. A reefer container is a type of cargo container that has an inbuilt refrigeration unit. The reefer container total power usage will vary depending on a variety of external factors. The increase in temperature caused by solar radiation on the walls of refrigerated containers has an impact on energy consumption. Furthermore, it necessary to consider the stack effect of the refrigerated container.

4. Conclusion

The CFD simulation of the reefer container has been carried out to analyze airflow distribution inside the cargo room. A study case of the load condition of skipjack tuna has been carried by two different types of floors and cargo load conditions. The simulation result shows the reefer container using the T-bar floor provides uniform air flow distribution compare with the flat floor. In the full load condition, all parts of the cargo obtained uniform cooling conditions due to vertical flow distribution from the T-bar floor. The optimum cooling condition archive at the air flow speed of 5 m/s with inlet temperature setting of -6°C. Furthermore, the optimum cooling time of reefer container with cargo load of skip jack tuna need to further analysis due according to load variation and environmental factors.

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