

Simulation of a Refrigerated Sea Water (RSW) Based Cooling System for a 30 GT Purse Seine Fishing Boat

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Abstract—Purse seine is a fishing vessel equipped with a special net used to collect, store, preserve, and transport fish catches. In the fish cooling process carried out by traditional fishermen in Indonesia, ice blocks are generally used. With the development of technology, a Refrigerated Sea Water cooling system has emerged. Refrigerated Sea Water (RSW) is a cooling system that uses seawater cooled by mechanical equipment. The mechanical equipment used to cool the seawater is a refrigerator. The purpose of this research is to design an RSW cooling system for a 30 GT purse seine fishing vessel at PPP Muncar to provide benefits to fishermen

Keyword—Purse seine, Refrigerated Sea Water (RSW), fish hold, refrigeration, fishing vessel.

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I. INTRODUCTION

Indonesia is a country with vast oceans and thousands of small islands that possess abundant fish resources. According to data from the Ministry of Marine Affairs and Fisheries, in 2023, total national fishery production reached 23.26 million metric tons, consisting of 6.04 million metric tons from capture fisheries and 17.22 million metric tons from aquaculture [1]. One of the most commonly used fishing gear by Indonesian fishermen is the purse seine.

The quality and freshness of the catch are key factors determining the market value of fishery products [2][3]. However, fish are highly perishable due to enzymatic and bacterial activity immediately after being caught. To slow down this quality degradation process, cold chain management directly on board the vessel is crucial [4].

Conventional cooling methods, such as the use of ice blocks, often have limitations, including uneven temperature distribution, the risk of physical damage to the fish's skin or flesh due to pressure from the ice, and low efficiency in utilizing the vessel's cargo space. As a solution, Refrigerated Sea Water (RSW) technology—a cooling system that utilizes seawater chilled by a refrigeration unit—is widely implemented on modern vessels [5][6]. RSW cools fish more quickly and evenly while preserving the fish's physical texture.

With technological advancements, the Refrigerated Seawater (RSW) cooling system has emerged. RSW is a cooling system that uses seawater cooled by mechanical

equipment [7][8]. The mechanical equipment used to cool the seawater is a refrigeration unit. The advantages of using this cooling system are that cargo space volume can be maximized, and the temperature of the fish will drop more quickly because the fish's surface comes into direct contact with the cooling medium.

However, the design and operation of RSW systems on board vessels require precise thermal and cooling load calculations. A simulation-based approach is crucial for analyzing system performance, chilling rate dynamics, and energy consumption without the need for costly experimental testing[10][11].

II. METHOD

A. Design Objective

Refrigerated Sea Water is a process for cooling fish by chilling seawater using a refrigeration system with mechanical equipment. The mechanical equipment used to cool the seawater is a refrigerator. The evaporator, which is part of the refrigerator, is mounted on one of the tank walls. This evaporator cools the seawater by absorbing heat released by the fish and the seawater itself [12].

The design of the refrigeration system in this study aims to produce a fish cooling system capable of lowering the product temperature from 30 °C to -5 °C within three hours using the Chilled Sea Water Spray Refrigeration (CSW-SR) method. Unlike conventional cooling systems that use single-pass seawater (once-through systems), this study employs a closed-loop recirculation concept, in which seawater is continuously cooled through the evaporator and then recirculated back to the nozzle to be sprayed onto the surface of the fish.

The system's design philosophy is based on the functional separation between the primary refrigeration cycle and the seawater cycle as the heat transfer medium. In this system, the refrigerant serves only to absorb heat from seawater through the evaporator, while seawater acts as a secondary medium that extracts heat from the fish and transfers it to the evaporator. Thus, the energy

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transfer path proceeds sequentially from the fish to the seawater, then to the refrigerant, and is finally released into the environment through the condenser. This approach results in a more stable system compared to a

once-through system because the temperature of the sprayed water can be maintained nearly constant throughout the cooling process, thereby ensuring more consistent cooling performance [13].

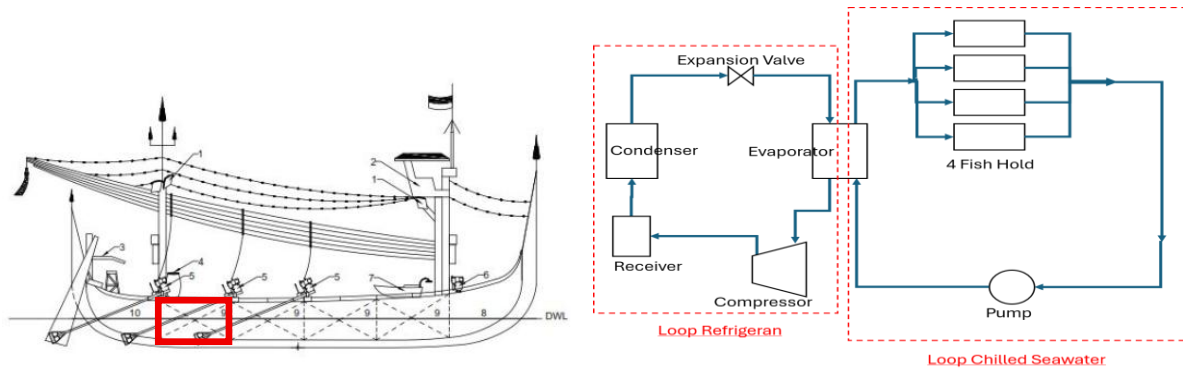


Figure 1. Keyplan RSW on Purse Seine Fishing Vessel

B. CFD simulation

In this study, simulations were performed using ANSYS Fluent software, which is a CFD software package based on the finite volume method (FVM) widely used in heat transfer and fluid flow analysis. In order to solve these equations numerically, ANSYS Fluent requires a computational domain in the form of a three-dimensional geometry that represents the actual physical conditions. Therefore, before the simulation process begins, a geometric model must first be constructed to serve as the solution domain for all numerical equations.

CFD simulations are carried out in three stages: preprocessing, solving, and postprocessing [14]. Preprocessing involves creating a model of the research object in Computer-Aided Design (CAD) format, generating a mesh based on the design, and then applying boundary conditions and fluid properties. CFD solvers (the core programs that find solutions) calculate the conditions applied during preprocessing. Meanwhile, postprocessing is the final step in CFD analysis. This step involves organizing and interpreting the data from the CFD simulation in the form of images, curves, or animations.

Geometry creation in this study was performed using Autodesk Fusion 360 as the Computer-Aided Design (CAD) software. External CAD software was chosen because it provides more comprehensive, flexible, and efficient geometry modeling capabilities compared to modeling directly within the ANSYS environment. Various operations—such as sketching, extruding, patterning, Boolean operations, filleting, shelling, and setting parametric dimensions—can be performed more easily, making the model-building process more systematic. Additionally, using CAD software allows for rapid geometric modifications should changes to dimensions or model configurations be required during the research process.

Once the base model is complete in Fusion 360, the geometry is exported to the ANSYS environment for geometry simplification and adaptation to the requirements of the CFD simulation. This stage aims to eliminate geometric details that do not significantly

affect flow phenomena, such as small features, overly complex angles, or geometric elements that could potentially degrade mesh quality [15][16]. Furthermore, this stage also involves checking domain continuity, adjusting model orientation, naming boundaries, and preparing the geometry to meet the requirements for meshing and simulation in ANSYS Fluent.

III. RESULTS AND DISCUSSION

A. Criteria, Design Principles, and Cooling Load Analysis

The initial design phase involves establishing the design basis parameters that will be used throughout the subsequent calculation process. By establishing the design basis from the outset, all system components will be designed based on consistent parameters, thereby avoiding the use of differing assumptions at each stage of the calculation.

To ensure that the design process remains systematic without losing accuracy in representing real-world conditions, several engineering assumptions were applied in this study. From a thermal perspective, it is assumed that the fish temperature is uniform and that there is no influence from solar radiation, air infiltration, heat from the crew, or product respiration. From a hydraulic perspective, it is assumed that the spray distribution is uniform, that the entire surface of the fish is exposed to seawater spray, that all water returns to the recirculation tank, and that water loss due to evaporation can be neglected. For the refrigeration system, it is assumed that operation occurs under steady-state conditions, the refrigerant pressure is stable, and heat loss in the piping network is negligible. These assumptions are commonly used in the preliminary design phase and aim to simplify the model so that the analysis focuses on the primary heat transfer mechanisms.

The basic design phase produces all the fundamental parameters that will be used consistently in subsequent design processes. Parameters such as total fish mass, total cooling load, refrigeration capacity, refrigerant operating temperature, and seawater operating temperature serve as references in the design of both the

primary refrigeration cycle and the seawater circulation system.

TABLE 1.
DESIGN BASIS OPERATION OF REFRIGERATION

Parameter	Value	Used In
Total Fish weight	11.144 kg	Cooling load calculation
Total cooling load	4.094 MJ	Cooling capacity
Design cooling load	436 kW	Compressor, evaporator condenser
Refrigerant	R404A	Refrigeration cycle
Evaporation temp.	-6 °C	Evaporator & compressor design
Condensation temp.	40 °C	Condenser design
Water temp. leaving the evaporator	-1,5 °C	Seawater loop design
Water temp. returning to the evaporator	2,5 °C	Seawater loop energy balance
Water System	Closed-loop recirculation	Tank, pump and nozzle design

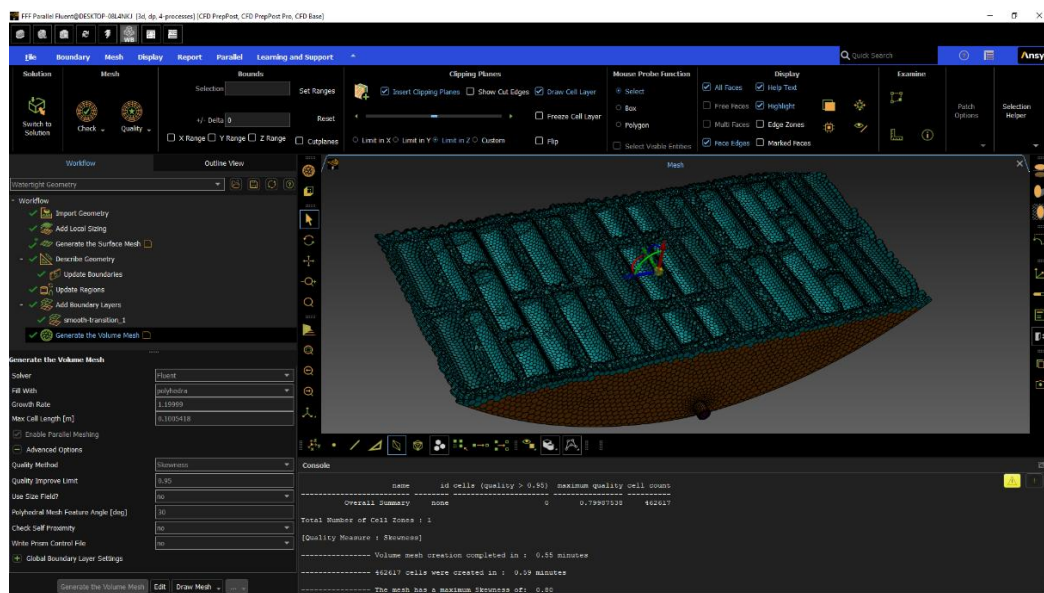


Figure 2. Meshing result display

B. Pre-processing and Quality Testing of Meshing for Numerical Methods

In ANSYS Fluent software, the pre-processing stage generally consists of two main processes: geometry preparation and meshing. Geometry preparation aims to ensure that the computational domain meets numerical requirements, such as the absence of gaps, overlapping surfaces, or non-manifold geometry. Once the geometry is deemed ready, the domain is then divided into a number of small elements through the meshing process. This discretization is necessary because the Finite Volume Method used by ANSYS Fluent solves the conservation equations for each computational element individually. Thus, the better the quality of the generated mesh, the more stable and accurate the resulting numerical solution will be.

The results of the meshing process show that the model with a 90% fish loading produced 462,617 cells, while the 70% loading produced 344,894 cells. The difference in the number of cells arises because the fluid volume in the two models differs, so the number of elements required to discretize the domain also differs. In general, the cell count is the total number of computational elements used by the solver to solve all the numerical equations. The larger the number of cells, the higher the model's spatial resolution, although this

results in increased computational time and memory requirements

In addition to the number of cells, another important parameter observed is Maximum Skewness. Skewness is a measure of the degree to which an element's shape deviates from its ideal form. Skewness values range from 0 to 1, where a value close to 0 indicates an almost ideal element, while a value close to 1 indicates a highly distorted element. In this study, both geometric variations yielded a Maximum Skewness value of 0.8. These values indicate that the elements with the largest deviations are still within acceptable limits, so overall, the mesh meets the basic requirements for CFD simulation.

When collecting data on upper and lower values, mesh skewness values of 0.5 and 0.8 were obtained in both variations. This data represents the number of mesh cells with values of 0.5 and 0.8. The objective is to determine the total number of cells within that range and compare it with other ranges. The evaluation results show that in the 90% fill variation, there are 505 cells with a skewness value of approximately 0.5 and 126 cells with a skewness value of approximately 0.8, bringing the total number of elements in the 0.5–0.8 skewness range to 631 cells. This is compared to a total of 462,617 cells.

This means that more than 99.86% of the elements in both models have a skewness value below 0.5, which falls into the “very good” to “excellent” categories. These results indicate that only a very small fraction of the elements fall into the “acceptable” category, while nearly the entire computational domain consists of high-quality elements. This suggests that the mesh used is of very high quality, capable of supporting a stable numerical solution process and yielding an adequate level of accuracy.

C. 3D Fluid Geometry Modeling of a Fish hold

The geometry developed in this study is limited to a single fish storage compartment, without modeling other components of the refrigeration system—such as the evaporator, pump, piping network, or nozzles—in detail. This simplification was made because the focus of the

study is to evaluate the fluid flow and heat transfer characteristics occurring within the fish storage compartment, rather than the mechanical performance of the entire refrigeration system. To assess the effect of the loading level on cooling characteristics, the model was created under two conditions: a compartment with 90% fish volume and a compartment with 70% fish volume. The 90% variation was used as the primary model because the entire analytical design was based on that condition; thus, the simulation results for this configuration will serve as the basis for the validation process. Meanwhile, the 70% configuration was used as an additional simulation to evaluate the effect of changes in load volume on flow distribution and heat transfer characteristics.

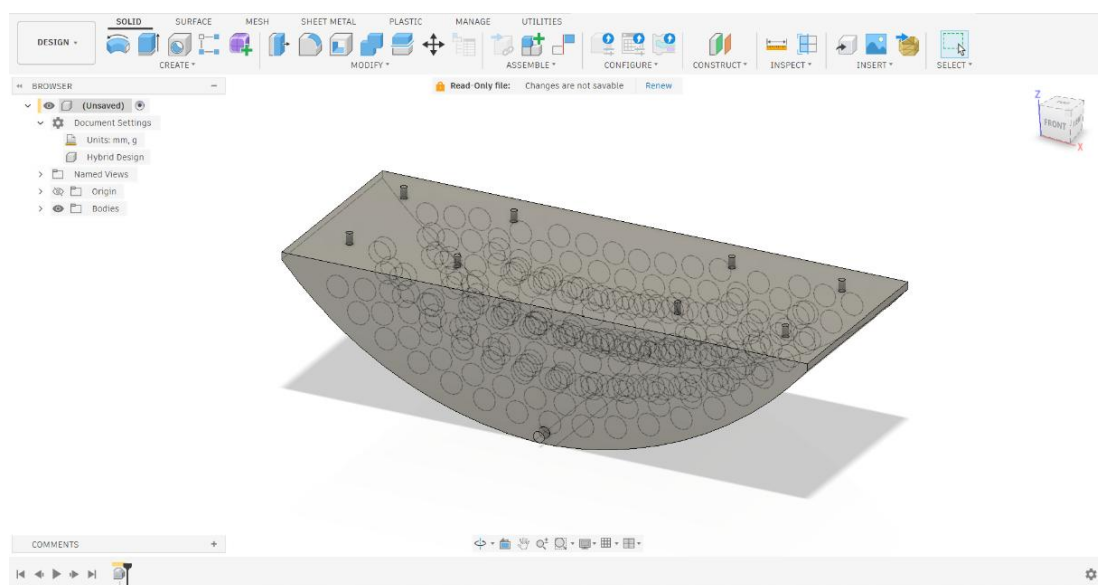


Figure 3. Modeling of fish hold

D. Analysis of the Effect of Hold Loading on Cooling Characteristics

In this stage, both variations were simulated using the same refrigeration system configuration, boundary conditions, spray flow rate, cooling water temperature, and operating time, so that any differences in the results were solely due to changes in the number of fish in the hold. The steps performed in this chapter constitute the post-processing phase using ANSYS Fluent. Post-processing is the process of analyzing the results of a numerical simulation after the iteration process is complete. Unlike the simulation phase, which focuses on solving the equations of mass conservation, momentum, energy, turbulence, and multiphase flow, post-processing aims to transform numerical data into easily understandable information through visualizations such as contours, vectors, streamlines, graphs, and other statistical parameters. This stage is crucial because the behavior of temperature distribution and heat transfer

within the fluid domain cannot be fully understood based solely on residual values or raw numerical data.

The primary parameters examined in this study consist of two variables: temperature distribution contours within the fluid domain and wall heat flux contours across the entire surface of the fish. These two parameters were selected because they illustrate two distinct yet interrelated phenomena. The temperature distribution indicates the refrigeration system's ability to distribute cold air and water mist throughout the entire hold volume, while the wall heat flux illustrates the actual intensity of heat transfer occurring between the fish and the cooling medium. As the number of fish in the hold increases, the total cooling load rises, causing the distribution of the heat load that the system must absorb to change as well. Therefore, the combination of these two parameters is considered the most representative for evaluating the effect of variations in hold loading levels on cooling performance.

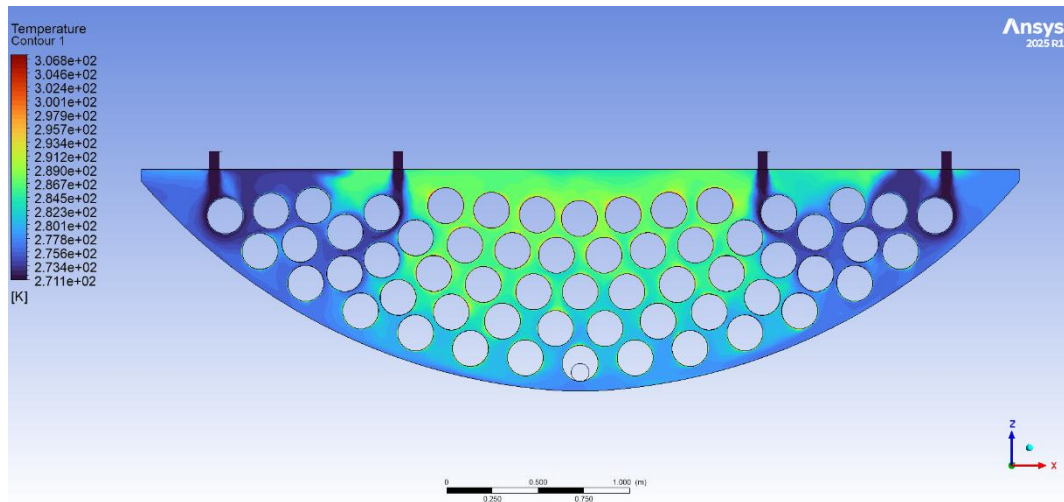


Figure 4. Temperature Contour Variation 90

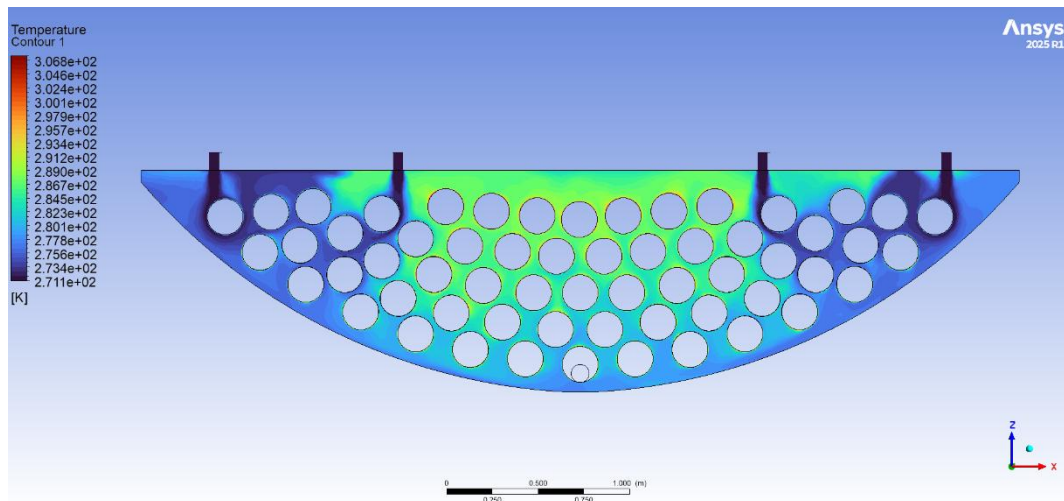


Figure 5. Temperature Contour Variation 70

Visually, the temperature contours in both variations show relatively similar distribution patterns, with variation 90 displaying colors corresponding to higher temperatures, meaning that variation 90 has a warmer average hold temperature. The areas with the lowest temperatures are still localized around the nozzle due to the inflow of cold seawater being sprayed, while higher

temperatures are found in the center of the domain. The color differences between the variations indicate a warmer temperature distribution in the 90 variation within the same temperature range. This occurs because the sprayed coolant has a high heat transfer capacity relative to air, resulting in a higher air temperature inside the hold.

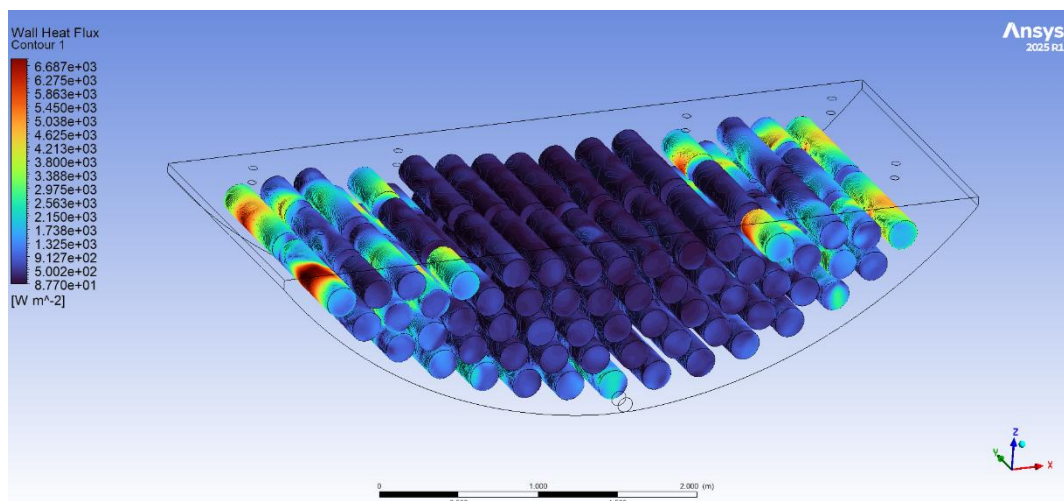


Figure 6. Contour Heat Flux Variation 90

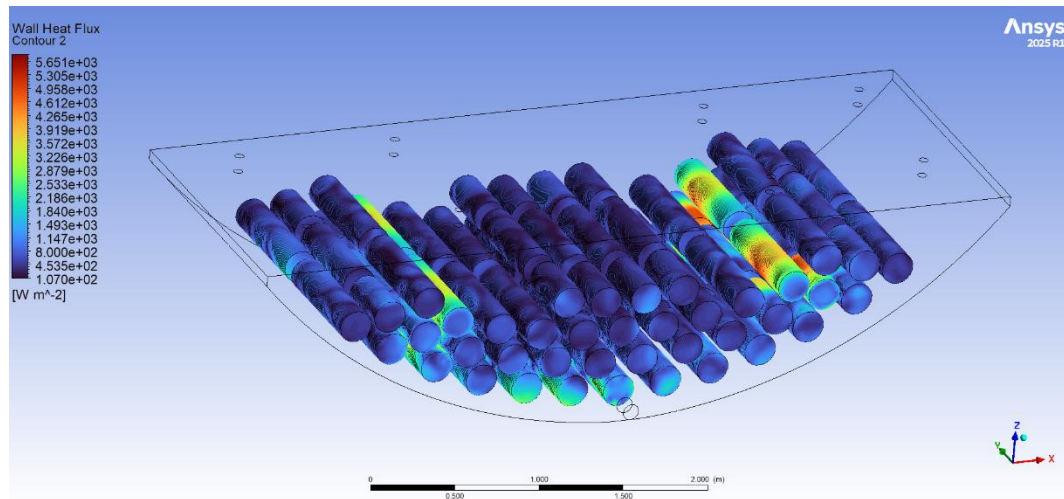


Figure 7. Contour Heat Flux Variation 70

The heat flux distribution shows much clearer visual differences. The 90% filling variation still shows areas ranging from green to yellow to red on some parts of the fish's surface, whereas in the 70% variation, most of the fish's surface is dominated by shades of blue to light green. Visually, these conditions indicate that the 90% variation still experiences greater heat transfer compared to the 70% variation. This suggests that the amount of heat the fish still needs to dissipate in the 90% variation is higher, meaning the cooling process is relatively less effective than in the 70% variation.

The range of values displayed on the contours provides crucial quantitative information that complements the visual observations based on color. The maximum heat flux in the 90% variation reached 6,687 W/m², whereas in the 70% variation it reached only 5,651 W/m². Thus, the maximum heat flux in the 90% variation was approximately 18.3% higher than that in the 70% variation. Conversely, the minimum heat flux value in the 70% variation drops to 107 W/m², whereas in the 90% variation it remains at 877 W/m², or about 87.8% lower. This difference indicates that the fish in the 70% variation experienced a greater reduction in heat transfer intensity compared to the 90% variation.

This phenomenon aligns with the theory of convective heat transfer. In the 70% stocking variation, the smaller number of fish results in a lower total cooling load on the system. With refrigeration capacity remaining constant, the available cooling energy is distributed across a smaller fish mass, so each unit area of fish surface receives a relatively larger cooling capacity. In addition, the reduced number of fish creates larger gaps between them, resulting in a more even distribution of the water mist and cold air. The surface area of the fish directly exposed to the spray also increases, making the local convective heat transfer coefficient more effective. Conversely, in the 90% variation, the fish surfaces are in close proximity, causing some areas to be shaded (shadowing effect), resulting in an uneven distribution of the cooling mist and requiring the cooling capacity to be distributed across a larger surface.

IV. CONCLUSION

The design of a refrigerated seawater-based cooling system with a closed-loop recirculation concept for a purse seine vessel's hold is based on calculations of product load, transmission, and solar heat. The total cooling load required to lower the temperature of pelagic fish (total mass 11,144 kg) from 30 °C to −5 °C within the target time of 3 hours is 4,094 MJ. Taking into account a 15% safety factor, the required design refrigeration capacity is 436 kW.

Refrigeration Capacity: Taking into account a safety factor of 15%, the required refrigeration system capacity is 436 kW. **Cooling Efficiency Characteristics (CFD Simulation):** 70% vs. 90% Load Capacity: The hold's loading level significantly affects cooling efficiency. A hold loaded to 70% capacity demonstrates a more effective and uniform cooling process compared to 90% loading.

Heat Flux Intensity: The maximum heat flux value at 90% loading reaches 6,687 W/m², which is 18.3% higher than at 70% loading (5,651 W/m²). This occurs because the density of the fish at 90% loading creates an obstruction effect on the cold water spray, whereas at 70% loading, the circulation of the cooling water spray can spread more optimally across the entire surface of the fish.

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