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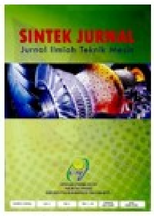

HEAT TRANSFER ANALYSIS OF SANDWICH PLATE SYSTEM APPLICATION AS INSULATION MATERIAL FOR FISHING VESSELS HATCHES BY FINITE ELEMENT METHOD

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ABSTRACT

Fish is a highly perishable food due to its suitability as a substrate for the growth of spoilage microbes, particularly bacteria. One method to maintain fish quality and extend its shelf life is preservation through a cooling system, where the duration of effective storage in the hatch is influenced by the quality of the insulation wall. Previous research modified the hatch insulation wall using a rice husk and white cement composition; however, these materials proved neither effective nor efficient in maintaining cooling temperatures. This study aims to determine the effect of heat transfer in a sandwich plate system on cooling time and temperature. Experiments were conducted using three variations in core layer thickness within a stainless steel-polyurethane-stainless steel configuration. The results indicated that at a temperature of 4°C, the maximum cooling times for each core layer thickness variation were as follows: variation 1 (3-20-3mm) lasted 62.5 hours, variation 2 (3-25-3mm) lasted 64 hours, and variation 3 (3-30-3mm) lasted 65.5 hours. The findings demonstrate that an increase in core layer thickness results in a prolonged maintenance of the cooling temperature within the hatch.

Keywords: Fishing Vessel Hatch Insulation; Finite Element Method; Heat Transfer; Sandwich Plate System.

ABSTRAK

Ikan merupakan bahan pangan yang mudah rusak karena cocok sebagai substrat bagi pertumbuhan mikroba pembusuk, khususnya bakteri. Salah satu cara untuk menjaga kualitas ikan dan memperpanjang umur simpannya adalah dengan pengawetan melalui sistem pendingin, dimana lamanya penyimpanan efektif di dalam palka dipengaruhi oleh kualitas dinding insulasi. Penelitian sebelumnya memodifikasi dinding insulasi palka dengan menggunakan komposisi sekam padi dan semen putih; Namun, bahan-bahan tersebut terbukti tidak efektif dan efisien dalam menjaga suhu pendinginan. Penelitian ini bertujuan untuk mengetahui pengaruh perpindahan panas pada sistem pelat sandwich terhadap waktu dan suhu pendinginan. Percobaan dilakukan dengan menggunakan tiga variasi ketebalan lapisan inti dalam konfigurasi baja tahan karat-poliuretan-baja tahan karat. Hasil penelitian menunjukkan bahwa pada suhu 4°C, waktu pendinginan maksimum untuk setiap variasi ketebalan lapisan inti adalah sebagai berikut: variasi 1 (3-20-3mm) berlangsung 62,5 jam, variasi 2 (3-25-3mm) berlangsung 64 jam. jam, dan variasi 3 (3-30-3mm) bertahan 65,5 jam. Temuan ini menunjukkan bahwa peningkatan ketebalan lapisan inti menghasilkan pemeliharaan suhu pendinginan yang lebih lama di dalam palka.

***Kata Kunci**: Insulasi Palka Kapal Perikanan; Metode Elemen Hingga; Perpindahan Panas; Sistem Pelat Sandwich.*

1. Introduction

Fish is highly perishable due to its suitability as a substrate for the growth of spoilage microbes, particularly bacteria [1-3]. One effective method to maintain fish quality and extend its shelf life is through preservation using a cooling system, where the duration of effective storage inside the hatch is determined by the quality of the insulation wall [4-6].

Several factors need to be considered when designing the construction of fishing vessel hatches, with the use of insulation being crucial to the fish cooling system [7-9]. Insulation in storage plays an essential role in ensuring the quality of the transported cargo. According to research, the use of insulated hatches as storage areas can significantly conserve ice during fishing operations [9-12]. The amount of ice remaining during landing and unloading is substantial, ranging between 20-30%, and can even reach 50% compared to storage without insulation.

As an insulation material for fishing vessel hatches, the primary expected quality is the ability to withstand external heat penetration, which is determined by the thermal conductivity properties of the material. In previous experiments [13], using 3 kg of wet ice, it was found that within a cooling time of 24 hours, a coolbox insulated with rice husks reached a lowest temperature of 13.5°C. In contrast, a coolbox insulated with Styrofoam achieved a lowest temperature of 10.6°C, indicating that rice husks are less effective than Styrofoam as an insulation material.

2. Methods

Data collection such as hatch geometry and thermal properties of stainless steel, polyurethane, ice cube, and fish cod. There are two constituent materials used in this research, on the surface layer of the hatch using stainless steel series 304 with a composition of 18% chromium and 8% nickel [14], the selection of stainless-steel series 304 because of the type of material in the hatch of fishing vessels must meet biological, sanitary, and hygiene requirements. In addition, the stainless-steel series is also widely used in the food and beverage industry.

Table 1. Stainless Steel 304 Thermal Properties

Density (kg/m^3)	Specific Heat (J/kg.°C)	Thermal Conductivity (W/m/K)
8.060	503	9.4

The material used in the hatch core layer uses polyurethane which is the result of mixing chemical reactions between polyols and isocyanates containing urethane groups (-NH-CO-O-) [15].

Table 2. Polyurethane Thermal Properties

Density (kg/m^3)	Specific Heat (J/kg.°C)	Thermal Conductivity (W/m/K)
1.300	1.700	0.28

Cod is one of the fish types from Gadus morhua species, which lives in the ocean. The most famous species of Cod are Atlantic Cod *(Gadus morhua)* and Pacific Cod *(Gadus macrocephalus)*. Then the cooling process in this simulation using ice cube with 0°C (273K) temperature [16].

Table 3. Cod Thermal Properties

Density (kg/m^3)	Specific Heat (J/kg.°C)	Thermal Conductivity (W/m/K)
1180	3.71	0.534

Table 4. Ice Cube Properties at 0°C (273K)

Density (kg/m^3)	Specific Heat (J/kg.°C)	Thermal Conductivity (W/m/K)
920	2040	1.88

3D models were designed using CAD software, hatches are modelled with 3 thickness variations on the core layer (polyurethane) with a thickness of 20, 25, and 30mm, and three variations of the core layer model covered with stainless steel plates in each variation i.e. 3mm.

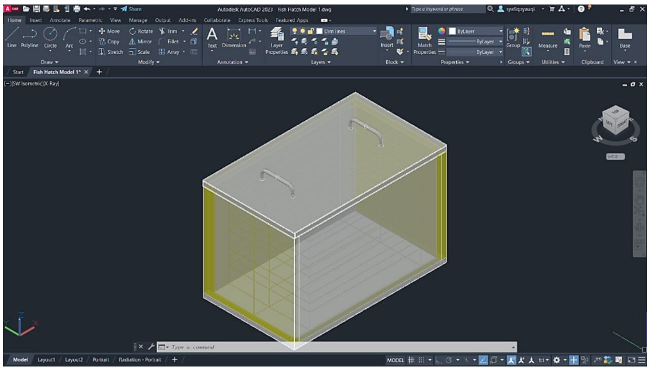

Figure 1. Making a Hatch Model using CAD Software

Table 5. Hatch Dimensions (Model 1)

Outer length	980mm
Inner length	928mm
Outer width	580mm
Inner width	528mm
Outer height	626mm
Outer height + hatch cover	655mm
Inner height	600mm
Hatch cover thickness	29mm
Insulation thickness	20mm

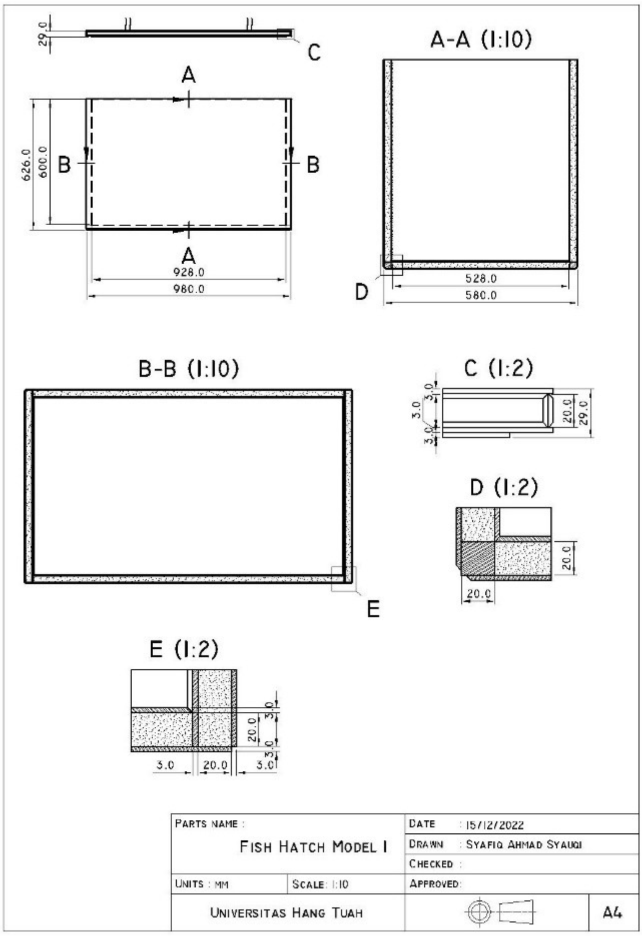

Figure 2. Hatch Dimensions Details (Model 1)

The hatch model fabricated using the SPS (Sandwich Plate System) method with a stainless steel-polyurethane-stainless steel material configuration. The determination of the layer thickness is based on the minimum allowable thickness of the bureau classification governing of the sandwich plate system application [17].

The arrangement of content in the hatch i.e., fish-ice-fish-ice, fish and ice are stockpiled with no more than 60 cm in height, so that the fish is not damaged and has a good texture [18].

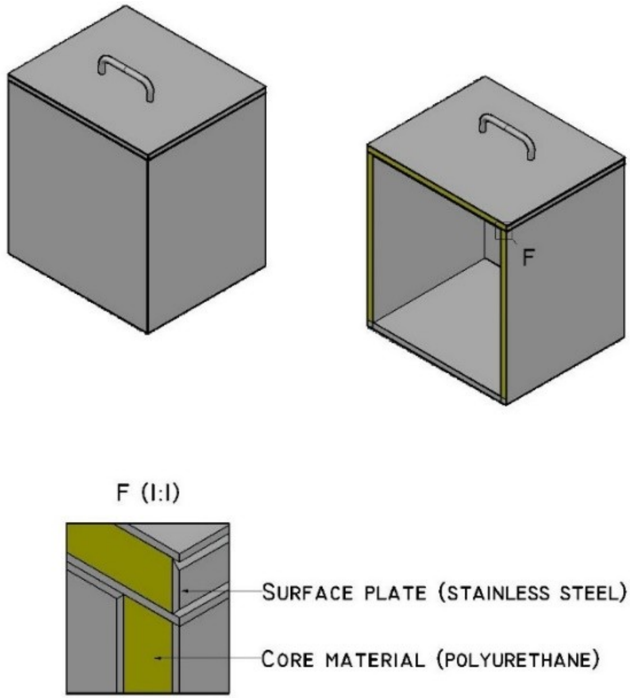

Figure 3. Hatch Wall Material Configuration

3. Results and Discussion

The calculation of the cooling load refers to ISO-7547 [19], which regulates the calculation of the cooling capacity needed, especially on the ships. Referring to ISO-7547, the outside air temperature in summer is +35°C (308K) with 70% humidity while the air temperature below deck is +27°C (300K) with 50% humidity, then the temperature design in the hatch room used in this research is 0°C or 273K. In this research, the calculation of cooling load is divided into two, the calculation of transmission load and radiation load. Transmission is generated due to heat transfer that occurs on the hatch insulation wall. Due to heat transfer through 3 materials, it is necessary to find the combined heat transfer coefficient using the following equation:

$$U=\frac{1}{\left(\frac{1}{f_0}+\frac{x1}{k_1}+\frac{x2}{k_2}+\frac{x3}{k_3}+\frac{1}{f_1}\right)} \quad (1)$$

The value of the air convection coefficient (*f0* and *f1*) is 4.5 W/m2. K obtained from the table of approximate values of air convection coefficient [20].

Table 6. Heat Transfer Coefficient Variable

Variable	Units	Model 1	Model 2	Model 3
f^0	$W/m^2.K$	4.5	4.5	4.5
f^1	$W/m^2.K$	4.5	4.5	4.5
$x^{1\,3}$ (stainless steel thickness)	m	0.003	0.003	0.003
x^2 (polyurethane thickness)	m	0.020	0.025	0.030
$k^{1\,3}$ (thermal conductivity of stainless steel)	$W/m^2.K$	9.4	9.4	9.4
k^2 (thermal conductivity of polyurethane)	$W/m^2.K$	0.28	0.28	0.28

Table 7. Total Value of Transmission Load

Models	Transmission load (Watt)					
	Up side	Down side	Front side	Back side	Right side	Left side
Model 1	38.516	29.712	33.555	33.555	19.859	19.859
Model 2	38.257	29.513	33.264	33.264	19.195	19.195
Model 3	38.028	29.336	33.003	33.003	19.802	19.802

Radiation load is a cooling load caused by the area of the outdoor wall that is directly exposed to sunlight. To determine the amount of radiation load, use the following equation:

$$\Phi_s = \sum A_v K \Delta T_r \quad (2)$$

The value of the indoor temperature difference used refers to ISO-7547, shown in the table 8 below.

Table 8. Value of The Surface Temperature of The Hatch Wall Exposed to Sunlight

Δ 12 K for vertical light surfaces
Δ 29 K for vertical dark surfaces
Δ 16 K for horizontal light surfaces
Δ 32 K for horizontal dark surfaces

At the top of the hatch (cover) has a higher temperature, this is because the surface is exposed to direct sunlight. On the front, back, left, and right sides, sun exposure only propagates through the surface.

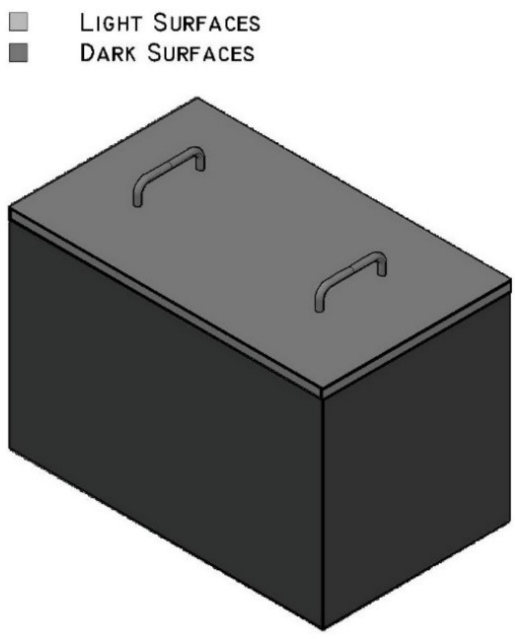

Figure 4. Illustration of Light and Dark Surface Radiation

The lower surface of the hatch is not exposed to sun exposure. So that the temperature difference value for each surface of the hatch wall is obtained as follows (Table 9 and 10).

Table 9. The Difference in Surface Temperature Values of The Hatch Walls Exposed to Sunlight

Models	Temperature difference, ΔT_r (K)					
	Up side	Down side	Front side	Back side	Right side	Left side
Model 1	32	0	29	29	29	29
Model 2	32	0	29	29	29	29
Model 3	32	0	29	29	29	29

Table 10. Total Value of Radiation Load

Models	Radiation load (Watt)						
	Up side	Down side	Front side	Back side	Right side	Left side	Total
Model 1	35.215	0.000	36.040	36.040	21.330	21.330	149.955
Model 2	34.978	0.000	35.728	35.728	20.617	20.617	147.669
Model 3	34.768	0.000	35.447	35.447	21.268	21.268	148.200

Based on the simulation result carried out in Figure 5, 6, and 7, temperature contours and graphs of the average temperature of fish against time were obtained.

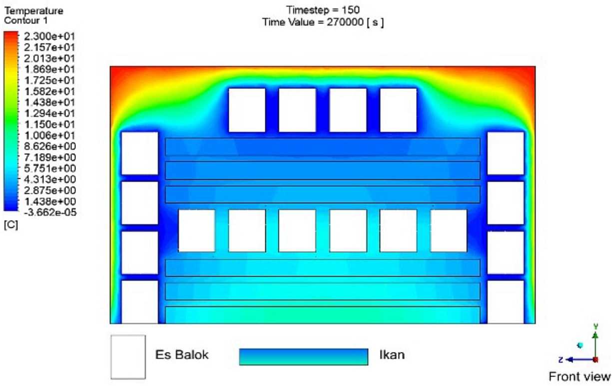

Figure 5. Temperature Contour Model 1

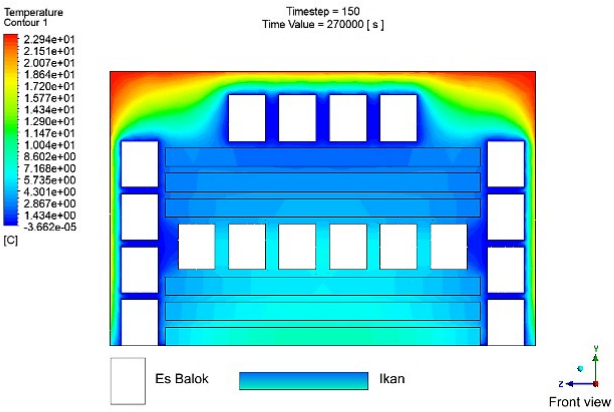

Figure 6. Temperature Contour Model 2

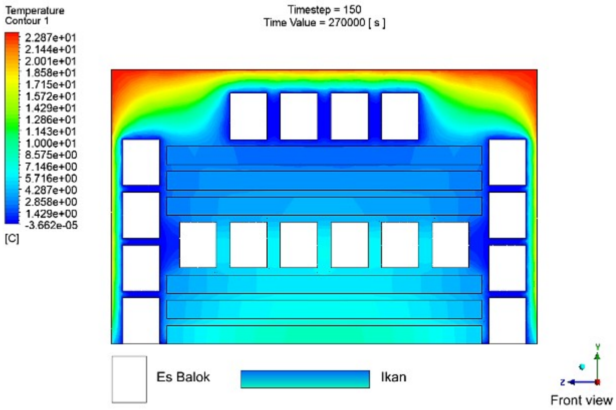

Figure 7. Temperature Contour Model 3

From the results of temperature contour on the three hatch models, there was no significant temperature difference in three variations in the thickness of the core layer of the insulation system. Furthermore, an increase in fish temperature is observed over time. It is intended to represent the capabilities of the sandwich panel insulation system.

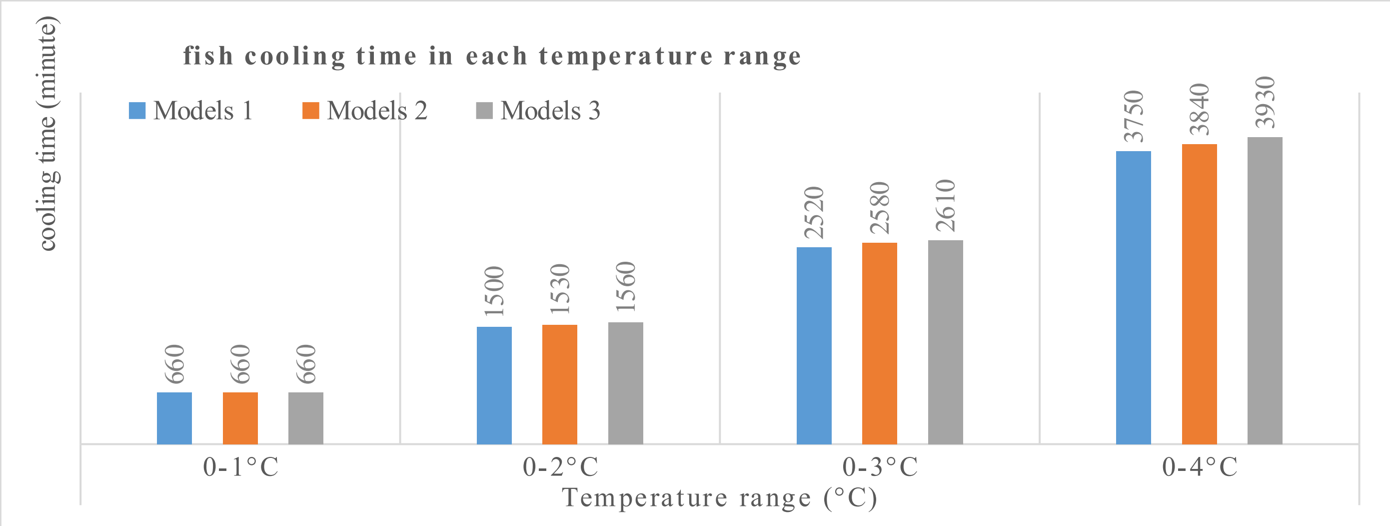

Figure 8. Graphic of Fish Cooling Time in Each Temperature Range

Based on the graph above, the cooling time of fish inside the hatch in the three models, respectively, experienced an increase. This indicates that the thicker the insulation layer, the longer the cooling time of the fish inside the hatch can be maintained longer.

Table 11. Fish Cooling Time in Each Temperature Range

Models	Cooling time (hours)			
	Temperature range (°C)			
	1°C	2°C	3°C	4°C
Model 1	660/ 11hr.	1500/ 25hr.	2520/ 42hr.	3750/ 62.5hr.
Model 2	660/ 11hr.	1530/ 25.5hr.	2580/ 43hr.	3840/ 64hr.
Model 3	660/ 11hr.	1560/ 26hr.	2610/ 43.5hr.	3930/ 65.5hr.

4. Conclusion

Based on the results of simulations that have been carried out, it was concluded that the use of sandwich plate systems as insulation materials in the hatch of fishing vessels can maintain cooling temperatures in the temperature range of 0 - 4°C with different duration of cooling time and temperature ranges in each variation in core layer thickness. The maximum cooling time that can be maintained is 65.5 hours or 2 and a half days at 4°C. The comparison of the maximum cooling time values in each variation in core layer thickness is: variation 1 (3-20-3mm) 62.5 hours, variation 2 (3-25-3mm) 64 hours, and variation 3 (3-30-3mm) 65.5 hours. The most ideal hatch model variation in maintaining the temperature inside the hatch is variation 3 with a core layer thickness of 30 mm with a cooling time of 65.5 hours at 4°C (Table 11).

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