Design of the Cabin in the Ultra Low-Temperature Refrigerated Vessel

Abstract: In the paper, some defects or shortcomings existed in the traditional cabin were considered, the new cabin of the globular was designed by means of AutoCAD software, and its three dimension model was built based on CAXA software. It was indicated from the calculation results that heat-transfer areas and heat-transfer capacity of the new cabin were smaller than the traditional one in the cases of the same external condition and volume of the cabin. Therefore, the performance of the heat preservation in the new cabin of the globular is better than the traditional one. At the same time, with the better property of the materials in the cabin wall and the higher technology of the refrigeration plant, the coefficient of the heat convection will be less, the performance of the heat preservation in the new cabin of the globular will be better also.

Keywords: Ultra low-temperature refrigerated vessel, Cabin, Design, Three Dimension model, CAXA, Heat-transfer area, Heat-transfer capacity.

1 Introduction

The ultra low-temperature refrigerated vessel is one of the very high technical standard ship types. The tuna fishery industry has taken up a dominant position in the deep sea fishing because of its high economic value and high nutritive value. The tuna will be frozen rapidly and saved and transported under −50 °C to keep its quality as far as possible. The transfer of the transport link can cause a rise of tem-
perature easily while affect the nutritional quality of tuna, therefore a rather high demand of the tuna’ low temperature storage and transportation is proposed. The existing cabin in the ultra low-temperature refrigerated vessel is of generally rectangular shape (or hexahedral type), and is simple to cooperate with other ship’s cabin and building layout. But the cabin also has the drawbacks or disadvantages of large heat transfer area and high rate of heat transfer, which need more refrigerating capacities to guarantee the same quality of the fish. Therefore, this study is to design a new type of refrigerated cabin structure and based on the existing refrigerated cabins and from the design requirement of refrigerating module of the ultra low-temperature refrigerated vessel. Its three dimension model was built based on CAXA software and from the heat transfer area and heat transfer in the cabin to verify its rationality.

1.1 Design Requirement Analysis of the Cabin in the Ultra Low-Temperature Refrigerated Vessel

Design requirements of the ultra low-temperature refrigerated vessel are determined by referencing the Rules and Regulations for the Construction and Classification of Sea Going Steel Ships and other ship design materials

1. Quick-freezing cabin and heat preservation cabin are coordinated effectively to reach a high-efficiency heat preservation (or cold insulation).
2. In the cases of the same volume of the cabin, reduce the heat transfer area and heat transfer capacity of the cabin and make good use of the ship cabin arrangement.
3. Quick-freezing cabin and heat preservation cabin are assigned reasonably to insure the ability of heat preservation.
4. Actual needs are met by reasonable design of the cabins in consideration of different volume and quality of goods and capacity of frozen cabinet.
5. In order to improve the cycle efficiency of the refrigeration cycle, the equipment of insulating door, hatch, bulkhead and air blower that are more convenient to transport goods are designed.

2 Design of New Ultra Low-temperature Refrigerated Cabin

2.1 Structure of New Ultra Low-Temperature Refrigerated Cabin

New refrigerated cabin of double-deck structure was designed by use of AutoCAD software as shown in Fig. 1, including the quick-freezing and insulation cabin.
The frozen body was spherical shape, the internal set of a thermal insulation cabin, the insulation compartment for the cylinder structure, and in the frozen body and the insulation compartment is equipped with two insulated doors on the wall to the insulation cabin, while the outer wall of the insulation compartment set up different sizes of quick-freezing cabinet arranged in the cabinet cooling coil, the cabin set more Typhoon fans to strengthen the air flow to ensure uniformity of the refrigeration temperature.

In addition, the quick-freezing cabin and the insulation compartment of the hatch are equipped with open or close the lid of the lifting device. The cabin structure on the use of quick-freezing cabin and the effective cooperation with the insulation can reduce heat loss and strengthen maintenance and management; The frozen body (or arc-shaped) as a whole, compared with the same volume of hexahedron (or rectangular), spherical body of the frozen body as a whole can reduce the compartment heat transfer area (or outer surface area). The use of quick-frozen and the insulation box effectively integrated into one can reduce the heat loss and strengthen the maintenance and management. At the same time, the hatch covers are used to start and stop the lifting device for the refrigerated and access to the goods to facilitate [3–4]

![Fig. 1: New cabin main view](image-url)
Fig. 2: New cabin top view

1–speed pulley; 2–compartment; 3–speed pulley; 4–compartment compartment; 5–coil; 6–compartment freezer; 7–fan; 8–compartment main body; 9–evaporative coil, 10–frozen chamber wall; 11–small cryogenic refrigerated area; 12–insulated door; 13–rotating shaft; 14–large bay; 15–evaporative coil; 16–quick freezing compartment; 17–Insulation compartment inner wall; 18–Frozen tank; 19–Insulation compartment; 20–Hook; 21–Conveyor equipment; 22–Insulation compartment cover; 23–Frozen cabin cover.

2.2 The Working Principle of the New Ultra-Low Temperature Refrigerated Cabin

As shown in Fig. 1, when the refrigerated tank cooling device is operated, when the frozen fish cargo is to be transported to the ship, the frozen fish stock transported from the deck is fed from the space chamber door 4 into the refrigerated compartment and opened by the pulley device 1. The quick-freezing compartment hatch 23 distributes the articles in a different refrigerated cabinet 6 according to the volume and weight of the fish stock.

After the quick freeze is completed and when the rapid freezing is required, the fan 7 is opened to speed up the freezing rate, and the frozen fish can be transferred directly to the insulation chamber 19 through the heat insulation door 12, where the quick-freezing tank 18 and the inside of the holding tank are common 15 and 17. The quick-freezing chamber fan 7 in the work increases the loss of heat within the quick-freezing compartment. The temperature is lower than the temperature inside the
insulation chamber, so that the quick-freezing compartment To the “cold” effect when the thermal insulation performance of the insulation compartment is affected, greatly improving the efficiency of the cabin and the refrigeration cycle of the cycle efficiency; When the frozen fish needs to be taken you will open the insulation compartment cover 22 through the pulley 3 to access to cold fish. When the cabin Internal cargo needs to be transferred quickly, you can open the large bay door 14 and delivery of goods quickly.

![Insulation bulkhead material selection](image1)

**Fig. 3: Material distribution of the bulkhead**

1–air layer; 2–steel plate; 3–heat resistant plastic; 4–foam; 5–mesh lithium alloy; 6–waterproof plastic; 7–coil;

### 2.3 Performance of New Ultra-Low Temperature Refrigerated Cabin and Material Selection

By the nature of the work of the cabin, the cabin to meet the cabinet, the outer wall material heat transfer coefficient as small as possible, that is, to reduce heat, the wall due to close to the evaporative coil, so it requires the greater the heat transfer coefficient, Therefore, the outer wall of the quick-frozen cabin steel material, the middle layer of foam, the wall selection of good heat transfer performance of lithium alloy, the only difference between the insulation compartment is the use of mesh wood. One of the steel plate fixed support cabin, plastic from the heat, waterproof and so on, the foam has a heat insulation, mesh wood can strengthen the insulation, protection coil, mesh lithium alloy with enhanced refrigeration and other functions [5–8], as shown in Figure 3.

As the cabin side of the wall directly from the heat source radiation and convection, heating up faster, and the bulkhead outside the large temperature difference, a lot of heat will flow through the bulkhead to the surrounding compartment, so its insulation performance should also have special requirement. In principle, Cold storage temperature to meet the design requirements of the minimum temperature, the continued cooling, to maintain the design requirements of the minimum tem-
perature of 8 hours or more to absorb latent heat, while 8 hours pressure rise is not greater than 1333Pa. One of the important characteristics of the wall of refrigerated cabin is its evaporative coil on its surface, and the effect of different types of evaporative heat exchangers on the wall is very different. Ship evaporation heat exchanger is mainly shell and tube or plate heat exchanger two, mostly for the shell and tube heat exchanger. Shell-and-tube heat exchangers have the advantages of strong construction, easy manufacturing, strong adaptability, large heat capacity, small pressure loss and good sealing. For the use of refrigerators (freon, etc.) as the cooling medium of the heat exchanger, its stability is higher. Plate heat exchangers have many uses on board, such as central cooler, piston water cooler, etc. It has the advantages of high heat transfer coefficient, compact structure, easy maintenance, easy to increase or decrease the heat transfer area, but its cost is higher. Easy to leak, so the design requirements of the cabin selection shell and tube heat exchanger is more suitable [9–11].

Fig. 4: CAXA model for new refrigerated compartments

Fig. 5: CAXA model for traditional compartments
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3 Modeling and Analysis of CAXA Model for New Refrigerated Cabin

3.1 Modeling of New Refrigerated Cabin CAXA Model

According to the design model of the new type of ultra-low temperature refrigerated cabin, the CAXA model is used as the modeling platform to establish the CAXA model of the new ball-type ultra-low temperature refrigerated cabin, as shown in Fig. At the same time, in the same volume V under the premise of the establishment of traditional hexahedron refrigerated cabin CAXA model, as shown in Figure 5.

3.2 Analysis of Cold Storage Capacity of New Type Refrigerated Cabin

Calculate the heat transfer area and heat transfer of the new compartments and the conventional compartments with the same volume V as the known conditions for the two chamber models to compare the refrigerated and heat preservation capacities of the new compartments and the conventional compartments.

3.2.1 Heat Transfer Area

Surface area of traditional compartments: $S_{\text{tradition}} = 6V^{\frac{1}{3}}$ (Assuming that the traditional refrigerated cabin structure is a regular hexahedron)

Volume of new compartments: $V_{\text{newtype}} = S_{\text{balt}} - 2V_{\text{sector}} = \frac{4}{3}\pi \cdot R^3 - 2\int_{h}^{R} \pi \cdot r^2 dh$, among them $r^2 = R^2 - h^2$. The surface area of the new compartment is:

$V_{\text{newtype}} = S_{\text{balt}} - 2V_{\text{sector}} = 4\pi \cdot R^2 + 2\pi \cdot r^2 - 2\int_{h}^{R} 2\pi \cdot r dh = (6\pi - \pi^2)R^2 + 2\pi(h \cdot r - h^2 + \frac{R^2}{2} \sin^{-1} \frac{h}{R})$ among them: $h$ for the new compartment height of the half; $R$ for the sphere radius; $r$ for the cylinder radius.

Thus according to the mathematical analysis method and limit the principle of reduction:

(1) At that time $0 \leq r \leq \frac{\sqrt{2}}{2} R$, hypothesis $r = k \cdot R$;

(2) At that time $\frac{\sqrt{2}}{2} R \leq r \leq R$, hypothesis $h = j \cdot R$; among them: Respectively, $k, j$ for the constant coefficient.
According to the decentralization method properly and respectively, when \(0 \leq k \leq 0.74, 0.67 \leq j \leq 1\), That is, the cylinder radius and the height of the cylinder are satisfied: \(0 < r < 0.74R\) or \(0.67R < h < R\), There is \(S_{\text{tradition}} > S_{\text{newtype}}\).

At the same time according to theoretical calculations, at that time \(r=0.74R\), which is \(h=0.67R\), at this time there are new cabin to meet the conditions in the case, the smallest heat dissipation area, which is \(k=0.74\), for the optimal proportion for the new compartment.

### 3.2.2 Heat Transfer \(Q\)

The heat transfer of the cabin and the outside of the ultra-low temperature refrigerated transport ship is mainly heat conduction and thermal convection. The heat transferred to the chamber by the cooling capacity of the chamber to the environment conforms to the Newton cooling formula, ie the convective heat transfer is: \(Q_{\text{tradition}} > Q_{\text{newtype}}\). among them: \(Q\) for the convective heat transfer, \(\alpha\) for the convective heat transfer coefficient, \(S\) for the heat transfer area, \(t_w\) for the external ambient temperature, \(t_f\) for the quick freezing/incubation chamber internal temperature. In the cabin insulation materials and internal and external environmental temperature difference are the same circumstances, according to Newton cooling formula: \(Q\) and \(S\) in the same external conditions are proportional, that is, to meet the design requirements, \(Q_{\text{tradition}} > Q_{\text{newtype}}\).

### 4 Calculate the Results

According to the calculation results of heat transfer area \(S\) and heat transfer \(Q\) in the new cabin and the traditional compartment, in the case of the same external conditions (bulkhead insulation and internal and external temperature difference) and the volume of the cabin, \(S_{\text{tradition}} > S_{\text{newtype}}, Q_{\text{tradition}} > Q_{\text{newtype}}\). That is, the heat transfer area and heat transfer capacity of the new type of refrigerated cabin are smaller than the heat transfer area and heat transfer of the traditional refrigerated cabin. Therefore, the new type of circular cabin is better than the traditional compartment.

### 5 Conclusion

This new type of spherical structure, to make up for the traditional hexahedron type heat transfer area, heat transfer and other deficiencies, for the ship cabin research and design to provide a strong basis. This kind of cabin has the practical operability,
and has wide application range, the remarkable effect of energy saving and so on, and can be widely used in medium, low temperature and ultra-low temperature refrigerated ship. With the further improvement of the inner and outer wall materials and the cooling device technology, the convective heat transfer coefficient is also reduced, and the new type of ultra-low temperature refrigerated cabin is better.

The design of the new type of ultra-low temperature refrigerated cabin is a preliminary study, and the rationality of the new refrigerated cabin is verified from the aspects of cold storage capacity. However, there are some shortcomings such as the selection of the new type of cabin and the reasonable connection with other compartments and ship buildings. The effective subdivision of the cabin and other aspects need further discussion and analysis. Therefore, the later research can be further studied from the research and development of ultra-low temperature refrigeration equipment, the research and development of new chamber experiment model, the experimental comparison of cold storage capacity of new and traditional chamber model, and the optimization design of new type of cabin structure.

Acknowledgement: The present research was partly funded by Zhejiang Province in 2013 major science and technology special, No. 2013C03033, Zhejiang Province higher education classroom teaching reform project, number kg2013194 and Zhejiang Ocean University, Port and Transportation School undergraduate students development of funding projects. Also, the research was supported by Zhejiang Ocean University.

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