

# Optimal Design of Heat Dissipation Scheme of Submarine Data Center Based on Multi-objective Programming

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**Abstract.** Aiming at the heat dissipation scheme of submarine data center, firstly, the main constituent materials of submarine container are screened by using deviation matrix; Secondly, considering the budget conditions, the water temperature equation is established, and the placement water depth and container wall thickness are determined by multi-objective programming method; Finally, considering the influence of seasonal factors and tidal factors, the influence of temperature on container heat dissipation is estimated. The research shows that: it is more suitable to choose AISI 1080 Steel as the material for the submarine data center under the conditions of comprehensive consideration of budget, water pressure, water temperature and other factors.

**Keywords:** All manuscripts, must be, figure texts.

## 1. Introduction

With the development of 5G technology, mankind has entered the era of billions of information [1]. The rapid development of information makes the number of servers in data centers around the world continue to increase, and the huge number of servers makes the cooling requirements of data centers continue to increase. According to the survey, the energy cost of equipment cooling accounts for 30%-50% of the entire IT industry. To address this situation, Microsoft first experimentally deployed a submarine data center in 2018. This low-cost, low-latency, high-security containerized submarine data center has received extensive attention from scholars at home and abroad since its construction. At present, China's submarine data center is still in the exploratory stage. Under this condition, the research on the selection of container materials for the submarine data center will provide a theoretical basis for the further development and implementation of the submarine data center. At the same time, it also provides a certain reference for the long-term construction of my country's IT business and information business.

At this stage, domestic and foreign scholars have conducted a lot of research on the design of the submarine data center, which mainly focus on the research and development of thermally conductive materials and the design of containers. In the field of material research and development, Han Zhidong et al. (2011) [2] prepared polymers with excellent thermal conductivity by compounding, using polymers with excellent comprehensive properties as the matrix and inorganic non-metallic materials with high thermal conductivity as fillers. On this basis, Wu Cong et al. (2018) [3] developed an alumina-epoxy resin that meets the heat dissipation material by using the powder gold method, and its thermal conductivity is higher than the general industry standard. In addition, Wang Chaoyu et al. (2022) [4] studied the internal structure of the material, built a three-dimensional thermal conductive connection network inside the material to reduce the interface contact thermal resistance between the materials and improve the thermal conductivity of the material. In the field of container design, on the one hand, Wang Yinghui et al. (2020) [5] proposed a method of using elliptical outer tubes with conforming fins for the container structure to optimize the current heat dissipation structure of finned tubes; on the other hand, Zhou Hao et al. (2021) [6] For material selection, using TOPSIS

analysis method, it is comprehensively concluded that Inconel 625 (Inconel 625) is suitable for the shell material of the submarine data center.

## 2. Data sources and model assumptions

### 2.1. Data sources

The data in this article comes from the question C of the 2021 MathorCup University Mathematical Modeling Challenge and the National Meteorological Science Data Center.

### 2.2. Concept definition

(1) The submarine data center: Install Internet facilities such as service areas in submarine airtight pressure vessels with advanced cooling functions, and use flowing seawater to dissipate heat from Internet facilities through heat exchange with seawater.

(2) Convective heat transfer: The energy transfer process caused by the relative displacement between the various parts of the fluid due to the macroscopic motion of the fluid. Specifically, as shown in Figure 1.

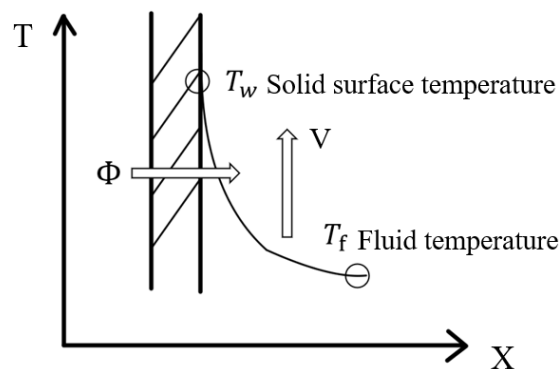


Figure 1. Convective heat transfer diagram.

(3) Permanent thermocline: not affected by seasonal changes, the water layer where the decrement rate is the largest in the process of seawater temperature decreasing with depth changes.

(4) Elastic Modulus: A physical quantity that describes the elasticity of a material, and is generally used to measure the ease of elastic deformation of a material. The larger the elastic modulus value, the greater the stiffness of the material, and the less likely to bend and deform.

(5) Yield Strength: A physical quantity that describes the stress experienced by a material when it yields, and is generally used to determine the maximum allowable load of material components.

(6) Tensile Strength: A physical quantity that describes the critical value of the transition of metal from uniform plastic deformation to local concentrated plastic deformation, which reflects the ability of the material to resist fracture. The higher the tensile strength, the less likely the metal material will break.

(7) Tidal change: a natural phenomenon that occurs in coastal areas, which refers to the periodic movement of seawater under the action of celestial tidal forces. The fluctuations in the vertical direction of the sea surface are called tides, and the flow in the horizontal direction is called tidal currents.

### 2.3. Model assumptions

In order to solve the problem, we put forward the following assumptions:

(1) Assume that the seawater density and specific heat capacity are fixed during the heat dissipation process.

(2) Assuming that the heat transfer surface of the container in the submarine cooling center is smooth, the heat can be released evenly through the shell and can be fully absorbed by the seawater.

- (3) The amount of seawater tends to be infinite, and the heat conduction is completed in an instant, ignoring the influence of time on the model.
- (4) In the absence of ocean currents, the seawater temperature in the vicinity of the container can be considered to be uniformly distributed.
- (5) Ignore the influence of special factors on the material itself.
- (6) It is assumed that the data center of this article will be placed in the South Sea of China.
- (7) It is assumed that the submarine data center is a cylinder with a length of 1m and a radius of 1m.

### 3. Selection of container materials

#### 3.1. Research ideas

First, according to the *Handbook of Oceanographic Engineering Materials*, find out the most suitable substances as ocean container materials. Secondly, considering the influence of ocean pressure and temperature on the container, determine the relevant physical properties of the material, such as elastic modulus. Thirdly, the relationship between the effect of ocean pressure on the material and the thickness of the material is analyzed. Finally, build a "water tank depth-container thickness finding model", and obtain the corresponding optimal solution.

#### 3.2. Data processing

##### 3.2.1. material selection

According to the materials given, materials that are not generally constituted as the main body of the container are removed. First, remove materials that are not suitable for seawater operations, that is, cannot be used in seawater or underwater and need to be used with caution. Second, remove materials that are absorbent, such as polymers, rubbers, and elastomers. Again, remove materials that are too expensive to host, like gold. Finally, since the South China Sea latitude is 4°N-21°N, materials that are not suitable for use at low latitudes are removed. Use the remaining 22 metals as alternate materials. Since this question needs to consider the material cost, we search for various material quotations through the buyer's market to determine the unit price (¥/kg). Assuming that the volume of the submarine data center is constant, it can be obtained from the physical density formula:

$$m=\rho V \tag{1}$$

The size of the available cost P (¥) can be determined by  $((P_0 \times \rho))$  ( $P_0$  represents the unit price of the material), so a comprehensive evaluation model is established with the four influencing factors in Table 1.

**Table 1.** Indicators of comprehensive evaluation model.

Index	Cost index	Benefit index		
Influencing factors	Cost (P)	Elastic Modulus (A)	Yield Strength (B)	Tensile Strength (C)

Then, standardize the four indicators, and obtain two deviation matrices according to the optimal plan: maximize the benefit index, minimize the cost index, and the worst plan: minimize the benefit index and maximize the cost index. The final result is as follows:

$$R = \begin{bmatrix} 0.05 & 0 & 0 & 1 \\ 0 & 0.58427 & 0.426415 & 0.01821 \\ 0.075 & 0.438202 & 0.388679 & 0.341758 \\ 0.6 & 0.479401 & 0.388679 & 0.276487 \\ 0 & 0.734082 & 0.709434 & 0.03154 \\ 0 & 0.794007 & 0.716981 & 0.031385 \\ 0 & 0.779026 & 0.754717 & 0.03154 \\ 0.1 & 0.835206 & 0.728302 & 0.07466 \\ 0.3 & 0.797753 & 0.709434 & 0.010899 \\ 0.675 & 0.535581 & 0.509434 & 0.515072 \\ 0.05 & 0.981273 & 0.822642 & 0.061722 \\ 0 & 0.928839 & 0.879245 & 0.097257 \\ 0.4 & 0.820225 & 0.822642 & 0 \\ 0.1 & 0.966292 & 0.773585 & 0.329635 \\ 0.6 & 0.902622 & 0.916981 & 0.002506 \\ 0.65 & 0.932584 & 0.898113 & 0.110059 \\ 0.6 & 0.93633 & 0.841509 & 0.232746 \\ 0.75 & 0.779026 & 0.766038 & 0.524964 \\ 0.75 & 0.925094 & 0.811321 & 0.286185 \\ 1 & 0.966292 & 0.973585 & 0.023587 \\ 1 & 1 & 1 & 0.023218 \end{bmatrix}$$

$$T = \begin{bmatrix} 0.95 & 1 & 1 & 0 \\ 1 & 0.41573 & 0.573585 & 0.98179 \\ 0.925 & 0.561798 & 0.611321 & 0.658242 \\ 0.4 & 0.520599 & 0.611321 & 0.723513 \\ 1 & 0.265918 & 0.290566 & 0.96846 \\ 1 & 0.205993 & 0.283019 & 0.968615 \\ 1 & 0.220974 & 0.245283 & 0.96846 \\ 0.9 & 0.164794 & 0.271698 & 0.92534 \\ 0.7 & 0.202247 & 0.290566 & 0.989101 \\ 0.325 & 0.464419 & 0.490566 & 0.484928 \\ 0.95 & 0.018727 & 0.177358 & 0.938278 \\ 1 & 0.071161 & 0.120755 & 0.902743 \\ 0.6 & 0.179775 & 0.177358 & 1 \\ 0.9 & 0.033708 & 0.226415 & 0.670365 \\ 0.4 & 0.097378 & 0.083019 & 0.997494 \\ 0.35 & 0.067416 & 0.101887 & 0.889941 \\ 0.4 & 0.06367 & 0.158491 & 0.767254 \\ 0.25 & 0.220974 & 0.233962 & 0.475036 \\ 0.25 & 0.074906 & 0.188679 & 0.713815 \\ 0 & 0.033708 & 0.026415 & 0.976413 \\ 0 & 0 & 0 & 0.976782 \end{bmatrix}$$

According to the cosine value of the angle between the two deviation matrices, the weights of the four influencing factors are determined, and the results are shown in Table 2.

**Table 2.** Weights of Influential Factors.

Influencing factors	Elastic Modulus $E$ (psi)	Yield Strength $\sigma_y$ (ksi)	Tensile Strength $\sigma_u$ (ksi)	Cost Index $P$ ( $P_0 \times \rho$ )
Weights	0.182046	0.27363	0.325682	0.218642

The materials are scored according to their weights, and the top ten materials are shown in Table 3.

**Table 3.** Material evaluation ranking table.

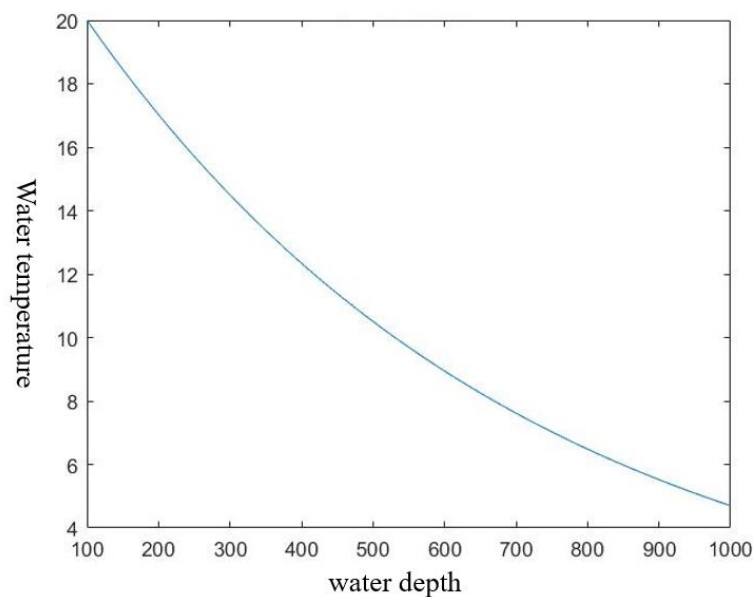
Material name	Unit Price ( $P_0$ / kg)	Density ( $lb/in^3$ )	Elastic Modulus (psi)	Yield Strength (ksi)	Tensile strength (ksi)	Cost Index ( $P_0 \times \rho$ )	Score	sort
Maraging 300 Steel	180	0.290	29	298	303	52.20	0.7723	1
AISI 1080 Steel	5.6	0.283	30	142	190	1.58	0.6973	2
17-4 PH Stainless Steel	65	0.281	28.5	181	200	18.26	0.6651	3
Beryllium-Copper CDA 172	50	0.298	18	170	200	14.90	0.5726	4
HY-100 Steel	8	0.284	30	102	115	2.27	0.5612	5
AISI 1040 Steel	8	0.283	30	86	113	2.26	0.5424	6
HY-80 Steel	8	0.284	30	90	103	2.27	0.5341	7
304 Stainless Steel	15.5	0.290	28	75	110	4.50	0.4997	8
Ductile Cast Iron	4.7	0.257	24	85	115	1.21	0.4937	9
Titanium 6Al-4V	170	0.160	16.5	155	168	27.20	0.4520	10

Note: When calculating the cost index P, the density has been converted into ( $kg / m^3$ ).

It can be seen from Table 3 that Maraging 300 Steel has the highest comprehensive evaluation score, and its yield strength and tensile strength indicators are good, but due to its high cost, this material can only be considered when the budget is sufficient. On a smaller budget, AISI 1080 Steel is recommended, which is not as good as Maraging 300 Steel in physical properties, but at a relatively low cost. Besides, under the general budget conditions, other materials like 17-4 PH Stainless Steel can be considered according to the focus of the physical properties of the material in the placement sea area.

**3.2.2. Determination of the water depth and the thickness of the box wall for the submarine data center**

The water temperature has a permanent thermocline between 100m and 1000m, while it is about 20°C at 100m and about 6°C at 1000m. Therefore, a water temperature equation can be established according to the logistic curve, as shown in Figure 2.



**Figure 2.** Schematic diagram of the change of water temperature with depth.

In the case of considering the budget, combined with the above conclusions, it was decided to use AISI 1080 Steel as the container material, and combined its properties into the model calculation. According to the logistic curve, through the differential equation, the ‘water temperature change formula’ is obtained as follows:

$$T = 20 \times e^{[-0.00160943 \times (h-100)]} (100 < h < 1000) \tag{2}$$

On this basis, we limit the thickness of the steel plate to 1cm-6cm. In addition, combined with the properties of AISI 1080 Steel, the goal is ‘the lowest water temperature and the lowest price of steel used’; the constraint condition is that it can withstand the water pressure. Using the multi-objective programming method [7-13] to establish a ‘depth-thickness searching model’.

Finally, genetic algorithm is used to find the Pareto optimal solution of this model. The shell thickness and placement depth of the submarine data center are comprehensively obtained. The results are shown in Table 4.

**Table 4.** Pareto optimal solution of the submarine data center placement depth and shell thickness.

Water Depth	Thickness	Price	Water Temperature (T)	lnT
100.0015598	0.035539294	27543.3796	19.99994979	2.99573
107.8259491	0.038487193	29828.03619	19.74967344	2.983137
110.6315704	0.040062389	31048.83244	19.66069579	2.978622
120.9770705	0.043550877	33752.45231	19.33604841	2.961971
127.0425363	0.045220788	35046.65358	19.14820934	2.952209
129.2362125	0.046651273	36155.29643	19.08072448	2.948679
132.1440928	0.048464455	37560.5341	18.99163476	2.943999
152.8014701	0.055501065	43013.99124	18.37060814	2.910752
159.4060933	0.056914738	44109.60489	18.17636866	2.900122
168.8131563	0.059996483	46497.99409	17.90325098	2.884982

## 4. Influence Mechanism of External Factors

### 4.1. Research Ideas

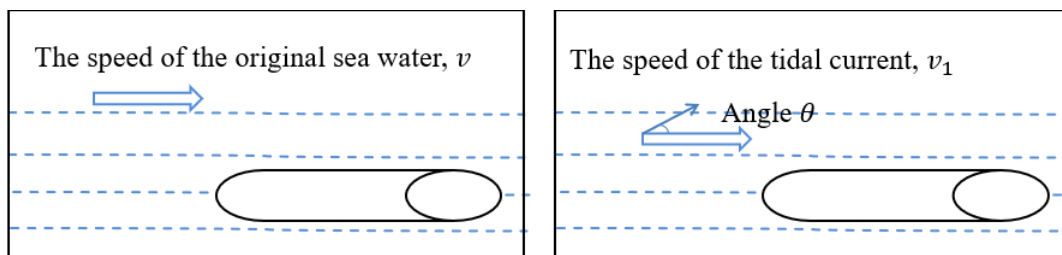
Because the influencing factors of the cooling effect of the submarine data center box are mainly tidal and seasonal changes. On the one hand, for the tidal phenomenon, we mainly analyze the following two situations, namely the fluctuation in the vertical direction—tidal, and the flow in the horizontal direction—tidal current [16]. By analyzing the effects of tides and tidal currents on water flow velocity, the impact on heat dissipation of the submarine data centers is analyzed. On the other hand, for seasonal factors, the discussion is mainly on the temperature situation. The effect of winter is favorable for heat dissipation, so it will not be discussed here. However, in summer, the increase in ocean temperature will affect the cooling efficiency of the submarine data center, so we will quantitatively estimate the specific impact of temperature changes on the submarine data center in the following.

### 4.2. Data Processing

#### 4.2.1. Model establishment under the influence of two tidal factors

(1) Model under tidal current conditions

① When the tidal current occurs, the angle between it and the flow direction of the raw water is  $\theta(0^\circ < \theta < 90^\circ)$ , as shown in Figure 3.



**Figure 3.** Diagram group of influence of tide on seawater ( $0^\circ < \theta < 90^\circ$ ).

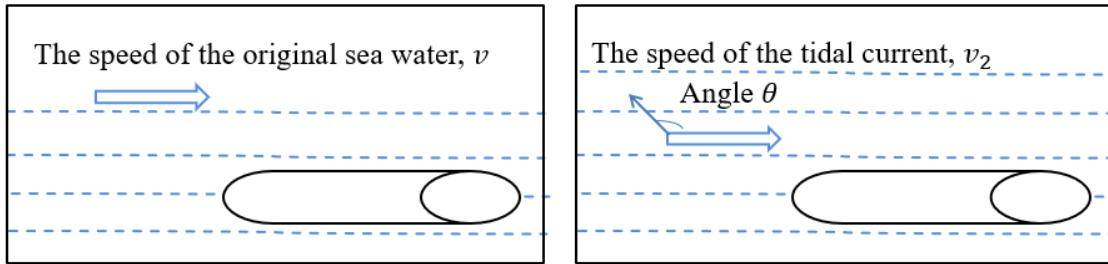
Assuming that there is no tidal current, the velocity of seawater is  $v$ , the velocity of  $v$  tidal current is  $v_1$ , and the included angle is  $\theta(0^\circ < \theta < 90^\circ)$ :

$$V = v + v_1 \sin \theta \tag{3}$$

Therefore, the time for the sea water to flow the longest distance of the submarine data center will be reduced, and the calculation result of the time difference caused by this phenomenon is as follows:

$$\Delta t_1 = \frac{12}{v} - \frac{12}{v+v_1 \times \sin \theta} \tag{4}$$

② When the tidal current occurs, the angle between it and the flow direction of the raw water is  $\theta(90^\circ < \theta < 180^\circ)$ , as shown in Figure 4.



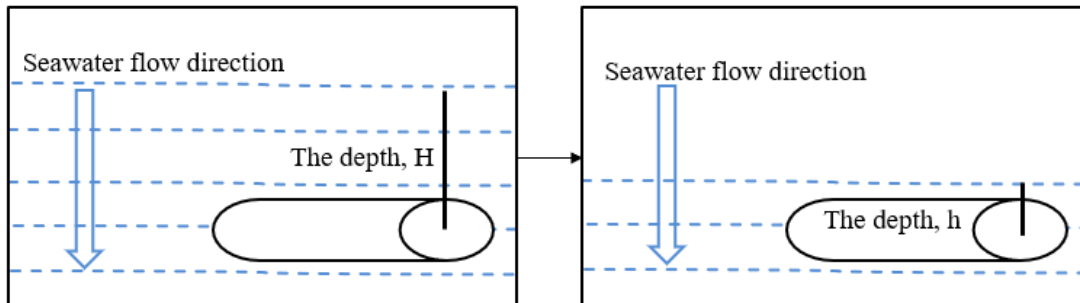
**Figure 4.** Diagram group of influence of tide on seawater ( $90^\circ < \theta < 180^\circ$ ).

Assuming that there is no tidal current, the velocity of seawater is  $v$ , the velocity of  $v$  tidal current is  $v_2$ , and the included angle is  $\theta(90^\circ < \theta < 180^\circ)$ . In the same way, it can be seen that the time for seawater to flow through the farthest distance of the submarine data center will increase. The calculation results of the time difference caused by this phenomenon are as follows:

$$\Delta t_2 = \frac{12}{v} - \frac{12}{v-v_2 \times \sin(1-\theta)} \tag{5}$$

(2) Model under tidal conditions

When the tidal phenomenon occurs, the vertical fluctuation of the sea surface occurs, which directly leads to the decline of the depth of the sea. As the seawater depth decreases, the temperature of the seawater around the submarine data center changes, which affects the heat dissipation effect [14], as shown in Figure 5.



**Figure 5.** Schematic diagram of tidal influence.

As shown in Figure. 5, ‘h’ represents the distance between the axis of the submarine data center and the sea level. At this time, regardless of the change of the horizontal seawater flow velocity, the depth difference after the tide is:

$$\Delta h = H - h. \tag{6}$$

The reduced temperature due to the difference in depth is:

$$\Delta T = 20 \times e^{[(-0.00160943 \times (\Delta h - 100))]} (100 < h < 1000). \tag{7}$$

At this time, the amount of heat reduction in convection heat transfer is:

$$\Delta \Phi = \alpha A(T - T_w) = \frac{T - T_w}{\frac{1}{\alpha A}} = \frac{\Delta T}{R}. \tag{8}$$

Therefore, the reduction in heat dissipation for the submarine data center, other things being equal, due to a drop in sea water level due to tides is:

$$\Delta\Phi = \alpha \times 38.465 \times 20 \times e^{[-0.00160943 \times (\Delta h - 100)]} (100 < h < 1000). \quad (9)$$

$\Phi$ : Convective heat transfer rate;  $A$ : Convective heat transfer area,  $m^2$ ;  $\Delta T$ : Convective heat transfer temperature difference,  $^{\circ}C/K$ ;  $T_w$ : Wall temperature in contact with fluid,  $^{\circ}C$ ;  $T$ : Average temperature of fluid,  $^{\circ}C$ ;  $\alpha$ : Convective heat transfer coefficient

#### 4.2.2. Model establishment under the influence of seasonal factors

Since the latitude of the South China Sea is between  $E105^{\circ}$ - $E118^{\circ}$  and  $N4^{\circ}$ - $N21^{\circ}$ , the data from the National Meteorological Science Data Center shows that the surface water temperature of the South China Sea is  $15$ - $18^{\circ}C$  in winter and  $28^{\circ}C$  in summer. The increase in seawater temperature may lead to insufficient cooling of the submarine data center. [15]

Assuming that the submarine data center should be placed at a depth of  $x$  meters, the temperature of the location where the submarine data center is placed is:

$$t_1 = 28^{\circ}C - \frac{x}{1000m} \times \frac{(1+2^{\circ}C)}{2}. \quad (10)$$

At this time, when the water temperature is  $t^{\circ}C$ , the normal working temperature of the server does not exceed  $80^{\circ}C$ , and the container is  $1 \times 1 \times 12$  m, the heat required for convective heat transfer is:

$$\Phi_1 = \alpha A(T - T_w) = \frac{T - T_w}{\frac{1}{\alpha A}} = \frac{\Delta T}{R} = \alpha \times 38.465m^2(80^{\circ}C - t_1). \quad (11)$$

End up with:

$$\Phi_1 = \frac{80^{\circ}C - t_1}{1/\alpha A}. \quad (12)$$

When the normal surface water temperature is  $20^{\circ}C$ , the submarine data center should be placed at a depth of  $x$  meters, and the temperature at which the submarine data center is placed is:

$$t_0 = 20^{\circ}C - \frac{x}{1000m} \times \frac{(1+2^{\circ}C)}{2}. \quad (13)$$

At this time, when the water temperature is  $t^{\circ}C$ , the normal working temperature of the server does not exceed  $80^{\circ}C$ , and the container is  $1 \times 1 \times 12$  m, the heat required for convective heat transfer is:

$$\Phi_0 = \alpha A(T - T_w) = \frac{T - T_w}{\frac{1}{\alpha A}} = \frac{\Delta T}{R} = \alpha \times 38.465m^2(80^{\circ}C - t_0). \quad (14)$$

Therefore, by comparing the amount of convective heat transfer that can be performed twice, the reduced heat transfer efficiency  $E$  is:

$$E = \frac{\Phi_1}{\Phi_0} = \frac{\alpha \times 9.42m^3(80^{\circ}C - t_1)}{\alpha \times 9.42m^3(80^{\circ}C - t_0)}. \quad (15)$$

The final solution is:

$$E = \frac{80^{\circ}C - t_1}{1/\alpha A} / \frac{80^{\circ}C - t_0}{1/\alpha A}. \quad (16)$$

## 5. Conclusions

Based on the above calculation results, it is found that Maraging 300 Steel has the highest comprehensive evaluation score, and its yield strength and tensile strength indicators are better, but due to its high cost, it is not suitable for large-scale use in the submarine data center. In order to control the budget, this paper proposes to consider AISI 1080 Steel as a material for large area use. Although the physical properties of this material are not as good as those of Maraging 300 Steel, its cost is lower than that of Maraging 300 Steel. In addition, other materials including 17-4 PH Stainless Steel can be considered according to the emphasis on the physical properties of the material in the placement sea area. According to the requirements of the environment and material usage of each part of the submarine data center, materials are combined for each component of the submarine data center, as follows.

① for the submarine data center's shells and pipes, the optional materials are Maraging 300 Steel, 17-4 PH Stainless Steel, AISI 1080 Steel, Beryllium-Copper, CDA 172, HY-100 Steel, Titanium 6Al-4V, Ductile Cast Iron, 304 Stainless Steel, AISI 1040 Steel, HY-80 Steel.

② for lightweight materials such as bearings, bushings, springs, etc., the optional materials are Beryllium-Copper, CDA 172, Cast Silicon Brass and Bronze, Cast Aluminum Bronze, Monel 400, Inconel 625, Titanium 6Al-4V, Acetal, Standard Homopolymer.

③ for wear-resistant parts, the optional materials are Polyurethane Elastomer.

④ for coatings, films, etc., the optional materials are Polypropylene, Nylon, Type 6.

⑤ for seals and gaskets, optional materials are Neoprene Rubber, Fluorocarbon Elastomers.

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