Energy Efficiency Pre-assessment on the Reactor Cabin Air Conditioning Cold and Hot Water System of Floating Reactor

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Abstract. The character of the Reactor cabin air conditioning cold and hot water system is analyzed, which is supported by a demonstration project of floating reactor, combined with environment conditions and requirements of standing wave sea area. On the basis of ensuring the stability and reliability of the system, the energy consumption of the system can be effectively reduced by using natural seawater and self high temperature steam absence as cold and heat sources, and the purpose of energy conservation and environmental protection can be achieved. Then, the conclusion is finally drawn: the system has good economic and environmental benefits, after the energy efficiency of the optimized system being pre-evaluated under the refrigeration conditions from Apial to November, including energy saving assessment and environment assessment.

1. Introduction

The floating reactor is a new type of mobile offshore nuclear power station that USES nuclear energy to generate electricity and then provides a three-dimensional combination of ship, nuclear and sea for island and offshore oil drilling platform. It is an organic combination of ship engineering and small nuclear reactor[1-3]. The project, currently owned only by Russia and still the first of its kind at home, will fill a gap in the country's maritime nuclear field[4]. The reactor compartment is the core compartment of the floating nuclear power platform, including the spent fuel storage compartment, the nuclear fuel handling compartment, the nuclear auxiliary equipment compartment and the containment vessel. The containment vessel is used to house and contain nuclear reactors[5-6]. As one of the important means of cold heat supply in reactor cabin, the cold and hot water system of air conditioning in reactor cabin plays an irreplaceable role. How to further save energy and environmental protection on the basis of ensuring the stability and reliability of the cooling and hot water system in the reactor cabin is a work of practical significance.

2. System introduction

2.1. System function

Under cooling and heating conditions, the stack cabin air-conditioning cold and hot water system is used to provide cold and heat sources for the air-conditioning device, fan coil, heating device and other equipment in the stack cabin. The air-conditioning refrigerant water produced by the stack cabin chiller takes away the heat in the stack cabin, and transfers the heat to the seawater through the stack cabin air conditioner chille. The air-conditioning heat medium water produced by the heating heat exchanger provides a heat source for the heating device in the reactor cabin.
2.2. Performance indicators

The design temperature and humidity of each area of the reactor cabin are respectively set as shown in Table 1 below. Based on this, the heat transfer of the envelope is calculated.

Table 1 Design Temperature of Containment and Reactor Cabin

| Area                                | Summer          | Winter         |
|-------------------------------------|-----------------|----------------|
|                                     | Temperature(℃) | Temperature(℃) |
| Containment                         | 50              | 50             |
| Spent fuel storage tank             | 35              | ≥5             |
| Nuclear fuel handling bay           | 35              | ≥5             |
| Nuclear auxiliary equipment compartment | 35              | ≥5             |

3. Re-evaluation of energy efficiency

The pre-evaluation indexes of energy efficiency of this system are mainly energy saving benefit and environmental benefit.

3.1. Pre-evaluation of energy saving benefit

3.1.1. Pre-evaluation content

Due to heating condition, this system adopts the steam-water heat exchange method preparation air conditioning hot water to provide heat source to the end of the heating device, and December to March under the working condition of refrigeration adopts the water-water heat exchange cooling method of terminal air conditioning device and fan coil units provide cold source from December to March. Therefore, the pre-assessment indicators of the energy-saving benefits of this system are the system energy-saving amount and energy-saving rate under refrigeration conditions from April to November (total 8 months).

3.1.2. Pre-evaluation process and calculation results

The accumulated cooling load of air conditioning in the refrigeration condition of this system is calculated according to the temperature and frequency method \[7\], and then the conventional energy replacement amount and energy saving rate are calculated based on the refrigeration energy efficiency ratio of this system. The power consumption under refrigeration condition from April to November of the system is calculated according to formula (1) below:

\[
E_c = \frac{Q}{EER_{sys}}
\]  

(1)

In the type: \(E_c\) is the power consumption of the system under refrigeration conditions from April to November (kW·h); \(Q\) is the accumulated air conditioning load of the system in refrigeration conditions from April to November (kW·h); \(EER_{sys}\) is the energy efficiency ratio of system refrigeration.

The annual energy of the system (that is, the replacement amount of conventional energy) is calculated according to formula (2) below:

\[
Q_c = Q - Q_b
\]  

(2)
In the type: Qc is the replacement amount of conventional energy converted into standard coal (tec, i.e. 1 ton of standard coal); Qt is the energy consumption of the traditional refrigeration system (tce); Qb is the energy consumption of the system (tec).

The energy saving rate is calculated according to formula (3) below:

$$\phi_a(\rho) = \left(2\pi \rho k \right)^{2/3} \exp\left[ik \cdot \rho\right]$$  \hspace{1cm} (3)

The final calculation results are summarized as shown in table 2 below.

### Table 2 Energy saving Benefit Evaluation of the System

| Index                                      | Cooling condition from April to November |
|-------------------------------------------|-----------------------------------------|
| Accumulative air-conditioning cooling load throughout the year/ (kW·h) | 1728000                                 |
| This system refrigeration energy efficiency ratio $EER_{sys}$ | 3.9                                     |
| Electric conversion into standard coal coefficient/ (tce/ kW·h) | 0.00033                                 |
| Traditional refrigeration system refrigeration efficiency ratio | 2.6                                     |
| The system consumes energy/tce            | 146.22                                  |
| Energy consumption of traditional refrigeration systems/tce | 219.32                                  |
| Conventional energy alternatives/tce      | 73.1                                    |
| Energy saving rate                        | 33.33                                   |

### 3.2. Pre-assessment of environmental benefits

#### 3.2.1. Pre-evaluation content

The environmental benefit pre-evaluation indexes of the system are mainly CO$_2$, SO$_2$ and dust annual emission reduction.

#### 3.2.2. Calculation process and results

The annual emission reduction of CO$_2$, SO$_2$ and dust was calculated according to equations (4), (5) and (6) as follows:

$$Q_{CO_2} = 2.47Q_c$$  \hspace{1cm} (4)

$$Q_{SO_2} = 0.02Q_c$$  \hspace{1cm} (5)

$$Q_{dust} = 0.01Q_c$$  \hspace{1cm} (6)

In the type: $Q_{CO_2}, Q_{SO_2}, Q_{dust}$ are CO$_2$, SO$_2$ and dust annual emission reduction (tce); $Q_c$ is the replacement amount of conventional energy converted into standard coal (tec, i.e. 1 ton of standard coal); 2.47, 0.02, 0.01 are the emission factors of CO$_2$, SO$_2$ and dust of standard coal, and are dimensionless coefficients.

Based on the above known data, the final results of the pre-assessment of the system's environmental benefits can be obtained by substituting the above formulas, which are summarized as shown in table 3 below.

### Table 3 Environmental Benefit Assessment of the System

| Indicators                          | Conventional energy alternatives | Annual CO$_2$ emission reduction | Annual SO$_2$ emission reduction | Annual dust emission reduction |
|------------------------------------|----------------------------------|----------------------------------|----------------------------------|-------------------------------|
| Numerical value                    | 73.1                             | 180.56                           | 1.46                             | 0.73                          |

### 4. Conclusion

Through the above optimization, the Reactor cabin air conditioning cold and hot water system of offshore floating nuclear power station is more perfect and efficient, which reduces the initial
investment, simplifies the system control process, reduces the later operation and maintenance workload on the basis of maintaining the system functions, saves human resources, and has good environmental and economic effects.

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