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Analytical and Experimental Feasibility Study of Combined OTEC on NPPs

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1. Introduction

Since the first oil shock, Combined Ocean Thermal Energy Conversion (OTEC) has gotten attention as reliable and renewable energy resource. In addition, several demonstration experiment have been performed.

However, because OTEC uses surface water which is about 30 ℃ as heat source, temperature condition of surface water could be satisfied only summer season in intermediate and high latitude. Hence, the concept of the Combined Ocean Thermal Energy Conversion (Combined OTEC) needs to study [1]. Combined OTEC uses exhausted steam on Nuclear Power Plants (NPPs) as heat source instead surface water. Exhausted steam extracted from condenser evaporates working fluid of Combined OTEC at heat exchanger (Hx-W in figure 1).

Essential calculation for conceptual design of Combined OTEC was already performed and presented before [2]. However, the technical issue whether sufficient extraction of exhausted steam from high degree of vacuum of condenser to Hx-W can be supplied or not was unclear, which is significant to continue a demonstration program. In this study, so, we calculated the rate of extracted steam to evaluate whether sufficient steam can be extracted using RELAP code.

2. Methods and Results

The degree of vacuum of power plants' condenser is maintained by condensation of steam. Combined OTEC uses this exhausted steam partially as heat source by extracting from upper part of condenser to Hx-W. Hx-W also maintains its degree of vacuum by condensation through heat exchanging with working fluid and steam like a power plans' condenser. Then, exhausted steam will flow into Hx-W to maintain the balance of pressure between condenser and Hx-W. To satisfy the temperature condition of heat source, however, it is possible that temperature of working fluid is higher than temperature of condenser circulation water. Then, it can cause relatively high pressure of Hx-W. So we calculated that sufficient steam can be extracted from condenser to Hx-W although condenser is almost vacuum.

Computer code used in the calculation is RELAP. This computer code developed by U.S. NRC for the transient analysis of light water reactor. RELAP is widely used to analyze thermal hydraulic behavior in the not only nuclear fields but also non-nuclear fields [3].

2.1 Concern about Combined OTEC

The OTEC has geographical and seasonal limits because OTEC should satisfy 20 ℃ of temperature difference [4], [5]. To compensate this, Combined OTEC uses exhausted steam.

In figure 1, it is confirmed that Hx-W is connected with condenser.

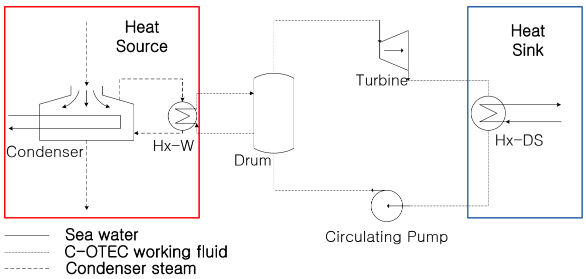

Figure 1. System arrangement of Combined OTEC.

Figure 1 shows schematic system arrangement of Combined OTEC.

Ideal temperature condition of deep ocean water is 4 ℃. But realistic temperature condition is considered to be between 4~10 ℃ because length of insulated pipe to intake deep ocean water is directly related to cycle economy. Accordingly, temperature of heat source should also become high to satisfy 20 ℃ of temperature difference and to maintain cycle efficiency economically. Hence, exhausted steam in Hx-W became to be condensed by higher temperature than temperature of condenser circulation water.

2.2 Feasibility Experiment

Due to the high degree of vacuum in condenser, there is a question regarding possibility of flow of exhausted steam to Hx-W. Verification about flow is directly connected with feasibility of Combined OTEC, so possibility of flow was confirmed by similarity experiment.

Experimental facility is composed of evaporator and two condensers. Figure 2 shows the diagram of experiment facility. 'Condenser 1' match plant's condenser and 'Condenser 2' match Hx-W. Using this facility, we confirmed that whether steam flowing into ‘Condenser 1’ flows into ‘Condenser 2.’

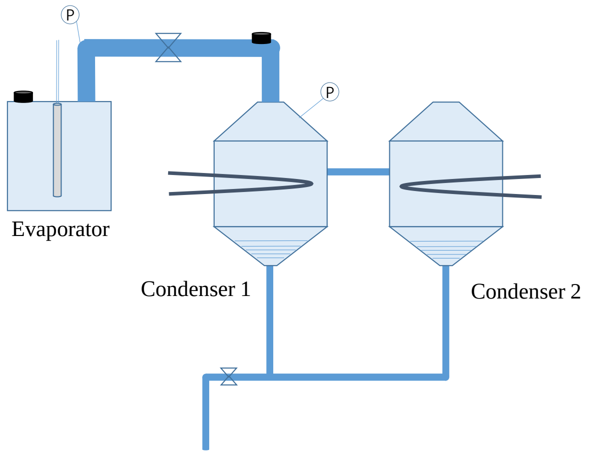

Figure 2. Diagram of experiment facility about feasibility of Combined OTEC

At the equilibrium state, condensation rates were measured. In the ‘Condenser 1,’ 60.6 % of total steam rate was condensed, and 39.4 % of total steam rate was condensed in the ‘Condenser 2.’

2.3 RELAP Simulation

Using RELAP code, after simulating the application of Combined OTEC to condenser, amount of exhausted steam flow rate depending on presence and absence of cooling capacity on Hx-W was calculated.

Initial condition of condenser and Hx-W were 10.0 kPa. And, temperature of circulation water and temperature of working fluid were 293.15 K and 298.15 K each. Calculation results are shown in figure 3.

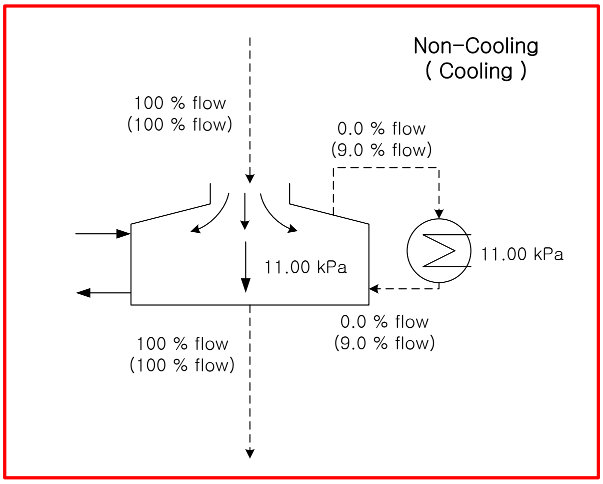

Figure 3. Comparison of extracted steam flow rate

In figure 3, Difference of initial flow rate of exhausted steam was caused by calculation characteristic of RELAP. We didn’t input the initial condition of flow rate but input the temperature and pressure conditions. Then RELAP found equilibrium state. Values in figure 3 are the value of final equilibrium state.

In case of non-cooling on Hx-W, there is no flow into Hx-W. In case of cooling on Hx-W, however, there is 9 % of total exhausted steam flow rate can be used as heat source for Combined OTEC.

3. Conclusions

In aspect of implementation of Combined OTEC, confirmation of sufficient flow of exhausted steam into Hx-W is the starting point of research. As the result of RELAP calculation, we confirmed that exhausted steam would flow into Hx-W. Considering the amount of exhausted steam in NPPs which is 1000 MWe and has 36 % of efficiency, 9 % of flow rate to Hx-W is means that 160 MWt of heat can be available as heat source of Combined OTEC.

Using this, it can be possible to improve efficiency of aged NPPs and can compensate power loss caused by increase of circulation water temperature particularly in summer season.

ACKNOWLEDGMENTS

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