Analysis of Combined Ocean Thermal Energy Conversion Using Waste Heat from NPPs

Hyeonmin Kim[a], Jeong-tae Cho[a], Hoon Jung[b], Gyunyoung Heo[a*]
[a]*Kyung Hee University, Yongin-si, Gyeonggi-do, 446-701, Korea*
[b]*Korea Electric Power Company Research Institute, Daejeon 305-760, Korea*
[*]*Corresponding author: gheo@khu.ac.kr*

1. Introduction

The project to use waste heat from power plant entitled "Development of Core Technology for Combined OTEC (Ocean Thermal Energy Conversion) using Plant Exhausted Thermal Energy" is being progressed with Korea Electric Power Company Research Institute (KEPCO RI). Ongoing project examines combined cycle by combining the C-OTEC (Combined Ocean Thermal Energy Conversion) generating 10 kW and a coal-fired power plant. After the project, it is expected to extend for a large-scale application.

C-OTEC had some advantage which generate additional electric power using waste heat from power plant and maintain condenser vacuums during, particularly, summer season. Since a nuclear power plant (NPP) experiences a loss of electric power of about 1% in summer, we attempted to suggest an alternative by using C-OTEC. In this paper, we proposed a conceptual design of C-OTEC with an NPP with heat balance calculations.

2. Methods and Results

2.1 Combined Ocean Thermal Energy Conversion

OTEC is a generating power system that it is using temperature difference between surface and deep sea-water. In real, the difference in sea water temperature at the equator and middle latitudes in summer is about 20℃. A temperature variation of 20℃ is known to be enough to operate OTEC. Actually temperature difference of operating OTEC is above 20℃. However, temperature differences in winter at middle latitudes are lower than temperature differences in summer. Thus, efficiency of OTEC is expected to decrease. This problem can be resolved if the heat source of OTEC can utilize waste heat from power plants. This cycle named C-OTEC.

C-OTEC is an electricity generation mechanism in that it uses the temperature difference between exhaust steam in condenser in plant and deep sea-water. Figure 1 represents a schematic of C-OTEC. Traditional plant was condensed to generate electric power by using a bulk of sea water. In this method, a ton of thermal energy was dumped into ocean. Operating process of C-OTEC is in following sentences. After connecting condenser to traditional plant and auxiliary condenser, working fluid in C-OTEC is evaporated by using exhaust steam. Evaporated steam is then moved to turbine and generates electric power. Thus, the problem of lower efficiency is in winter is resolved and therefore, maintained efficiency of plant during any seasons. The cycle in Figure 1 shows, main condenser is the existing condenser, a primary condenser is charge of role of evaporator and a secondary condenser is charge of condensing working fluid.

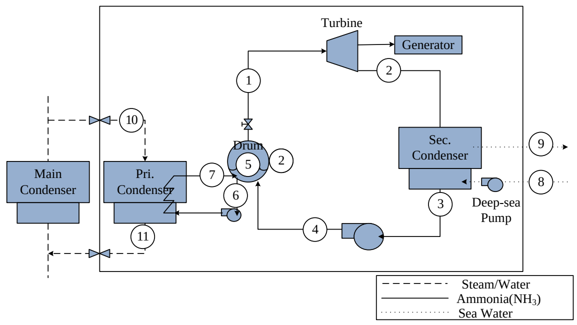

Fig. 1. Schematic of C-OTEC

2.2 Simulation of C-OTEC

Until present, C-OTEC does not put to practical use. Thus we need efficiency of turbine of low pressure/low temperature and practical measures for exact modeling. It will be obtained during progressive project with KEPCO RI.

Basic operating condition for modeling was obtained from a previous study [1]. Total modeling for C-OTEC was performed by using EES (Engineering Equation Solver). Working fluid of C-OTEC was selected as ammonia (NH_3) same as used in a reference. Design conditions of steam from main condenser to primary condenser created to get net power 5MWe and existing enthalpy to obtained same power at reference. Operating pressure in C-OTEC was assumed 1,000 kPa in order to trigger vaporization using exhaust steam. For detailed performance properties of C-OTEC represents Table I. Deep sea-water pipe assumed large pipe, thus, avoids calculation of pressure drop and heat transfer.

For the comparison of accuracy of the modeling cycle, the gross efficiency was 3.1%. Net power considering total pumping power was 2.5%. With the similar conditions, efficiency of referenced cycle was 2.5%. Although efficiency of calculated cycle was higher than it was for referenced cycle, practical efficiency considering availability was much higher.

Table I: Performance properties in C-OTEC

No. (Fig.1)	P (kPa)	T (℃)	x	$\dot{m}$ (kg/s)	Fluid
1	1,000	24.89	1	184.5	NH_3
2	667.8	12.39	0.9	184.5	NH_3
3	647.8		0	184.5	NH_3
4	1020			184.5	NH_3
8	101.3	4		10,424	Sea Water
9		15		10,424	Sea Water
10	5		0.9	104	Steam
11		32.88	0	104	Steam

2.3 Impact on NPPs

In this chapter, we would like to explain the comparison of power by generating through combined cycle and only by a NPP. Simulation of nuclear power plant was performed by using PEPSE (Performance Evaluation of Power System Efficiency). The results of C-OTEC was input to the model of the NPP and an integrated simulations have been performed.

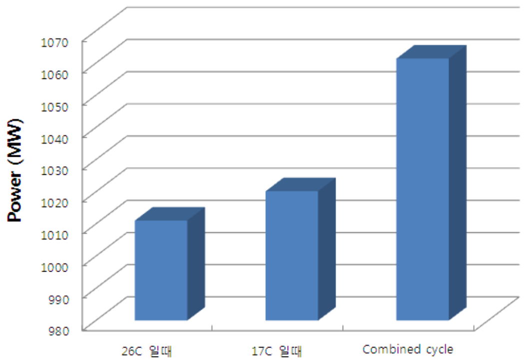

Fig. 2. Comparison of electric output for C-OTEC only and with an NPP

Figure 2 represents comparison of power of an NPP plant (design output: 1,000MWe) as sea water temperature at 17℃, 26℃ and that of C-OTEC. When cold sea water comes, condenser vacuums decrease. In this case, decreasing condenser vacuums results in increase of electric power. However, it is not always possible to supply enough sea-water to control an optimal condenser vacuum. Thus lowest power occurred with sea water temperature at 26℃ but highest power occurred with sea water temperature at 17℃. In Figure 2, electric power calculated 1,011 MWe at former case, latter case calculated 1,020 MWe. Difference in two cases calculated about 9 MW or almost 1% of design capacity. Total power from combined cycle calculated 1,061 MWe. Additional electric power from combined cycle was 50 MW. It was calculated to compare traditional power plant and C-OTEC in the summer, 26℃ case.

3. Conclusions

Combined cycle has some advantages. Main advantage among some advantage maintained condenser vacuums in any seasons. It is possible to generate constant electric power from existing plant and additional electric power from OTEC.

Ongoing project which is mentioned in this paper will also verify the validity of underlying assumptions in modeling for C-OTEC such as technical data of condenser, heat exchanger, and turbine which operate low pressure and low temperature. Furthermore, next research will consider some problems like, suitability of working fluid, safety problem from leak due to connecting auxiliary condenser, suction problem of deep-seawater, and economical analysis. It is expected that C-OTEC will be competitive against other renewable energy such as solar power generation and wind power generation.

ACKNOWLEDEMENT

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