Mitigation of Environmental Impact of Power-plant Discharge by Use of Ocean Thermal Energy Conversion System

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***Abstract*- This study aims to evaluate the mitigation method of environmental impact of power-plant discharges by reducing the temperature difference between effluent and coastal water. To minimize excessive thermal pollution which could cause serious socio-economic problems, Ocean Thermal Energy Conversion (OTEC) system can be applied to control the resultant temperature of combined discharge as well as to produce electricity by reusing the warm discharge from power-plant as a heat source for OTEC. Adaptability analysis of closed cycle OTEC was examined to 350MW fossil fuel power plant. The results show that combined system could mitigate the thermal discharge effectively if suitable size of OTEC is connected with the power-plant. Furthermore, this method gives us marine forest to absorb carbon dioxide which may be altered to green house gas emission credit as well as clean electric power.**

I. INTRODUCTION

A lot of power plants have been constructed along the coasts in the world to produce electric power efficiently. They are pumping up more hundred thousands tonnage of seawater every day as a heat sink in thermal power plant. Through the cycle, heat waste has been emitted out to environment of river or sea. Though such thermal discharges have been made through various human-living and industrial activities from ancient time, the amount was not so severe to aquatic ecological system. Not negligible effluent has been reported since industrial revolution in 19C. Environmental impact of thermal discharge from many factories and plants along the coasts, especially huge power plants, has been big issue in the socio-economic viewpoints of coastal eco-system[1].

Power-plant discharges in advanced nations of industry take places in 80 to 90% of whole thermal effluents. The amount is increasing with expanded demands of energy consumption. In Korea, more than 60 million tonnage of warm cooling water is being discharged from power plants into coastal zone.

Environmental impact of thermal discharge from power-plants against surrounding industry and activity has caused controversial issue as the lawsuits for compensation. The first compensation of the impact was made by the suit called 'Pride of Derby' in British, which resulted in paying 25% of damage in fisheries production. At last, power-plant discharges have been dealt with thermal pollution in the world wide since the historical event[1].

Various measures have been proposed and adapted to minimize the thermal pollution from the plants. However, almost methods to mitigate the impact might be still less effective in that there is no noticeable reports to settle the thermal pollution problems.

From such background, DOWARC(Deep Ocean Water Application Research Center) is going to study a series of applying deep seawater as 1) indirect use by OTEC(Ocean Thermal Energy Conversion) system combined to reuse the warm power-plant discharge, 2) a direct use of cooling water for power-plant, and 3) integrated combination of cascade use of deep ocean water[1] and the warm discharge water for OTEC, SWAC(Sea Water Air Conditioning), aqua-cultural and agricultural application and so forth. Among them, this study is on the assessment of applicability of OTEC to power plant in order to produce electricity as well as to mitigate the environmental impact of power-plant discharge.

II. OCEAN THERMAL ENERGY CONVERSION SYSTEM WITH INTAKING AND DISCHARGING OF SEAWATER

The ocean thermal energy conversion (OTEC) is a system designed to transform the thermal energy by temperature difference between cold deep seawater and warm surface water into electricity. The method for OTEC is using turbine and thermal transfer, and OTEC is mostly operated by turbine cycles which are classified into as a closed cycle, an open cycle, a hybrid cycle, a moisture cycle, a foam cycle.

Basic system of OTEC is the closed cycle, which is composed with evaporator and condenser by heat exchanger, refrigerant, circulation pump, turbine generator and intake pipelines etc. In general, it requires at least 17°C of temperature difference between warm seawater from surface layer and cold seawater from deep layer. Heat source can be substituted by other sources as waste heat or solar power etc.

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The operation of a closed-cycle OTEC plant with ammonia as the working fluid is modeled with the saturated closed cycle. Schematic diagram of a simple Rankine cycle is shown as Fig. 1. The analysis of the cycle is straightforward shown in Fig. 2. Based on a unit mass flow rate of ammonia vapor in the saturated cycle, the balances of heat and work can be calculated as follows;

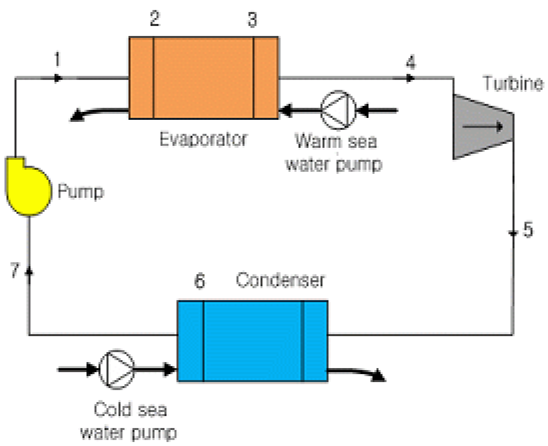

Figure 1. Closed cycle OTEC flow diagram.

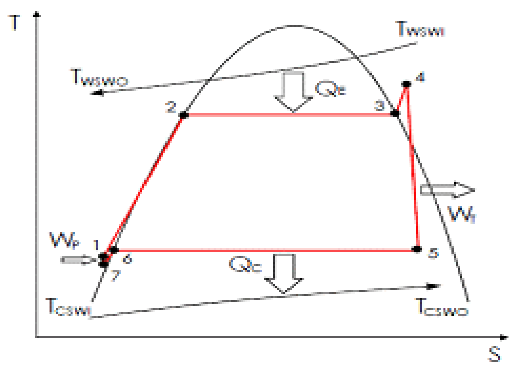

Figure 2. T-s diagram of the system.

Heat evaporated (J/kg) : $Qe=h4-h1$ (1)
Heat condensed (J/kg) : $|Qc|=h5-h7$ (2)
Pump work (J/kg) : $|Wp| = h1 - h7$ (3)
Turbine work (J/kg) : $Wt = h4 - h5$ (4)
Cycle net work (J/kg) : $Wnet = Wt – Wp$ (5)
Thermal efficiency : $Et = Wnet / Qe$ (6)

where, hi is the enthalpy at the indicated state point. It follows that the evaporated heat plus the work of pump is equal to the condensed heat plus the work of turbine[3].

III. Discharging Rate and Temperature Difference of Power-Plant Discharge

Intake and discharge rate of cooling water for power-plant are inclining with enlarging the size of fuel-fired and nuclear power plants. As the scale of unit power-plant was merely 0.1 MW in 19C, it become bigger than 500MW in fuel-fired power-plant and bigger than 1000MW in nuclear power plant. Though the required amount of cooling water per unit plant decreased one-sixth based on the advancement of technology, total worldwide amount increased more than 7 times[2].

Because intake water from river or lake can not meet the tremendous demands of cooling water for modern power-plant, almost plants locate along coasts to use sufficient seawater. Nuclear power plants were constructed at 422 sites along the worldwide coasts; they generate 360 million kW of electricity in 37 countries until 1998. It shares 17% of world power production. Korea has 16 nuclear power-plants to generate 13.72 million kW in 2000, those cover 40% of whole production of electricity[2]. According to the expansion of power-plants shown in Fig. 3 along the Korean coasts, power-plant discharges are proportionally increasing year by year.

Figure 3. A view of power-plant in Korea.

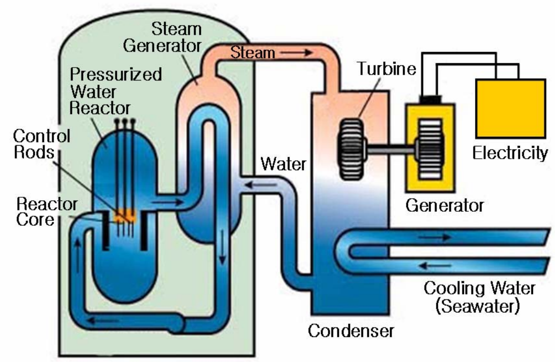

Figure 4. Process diagram of cooling water for the power-plant.

As shown in Fig. 4, cooling water is discharging through condenser of power-plant with increased temperature of 10~12℃. Resultant temperature of the discharge is regulated under 40℃ to avoid critical damage of thermal pollution in Korea. Thermal effluent is from not only power-plants, but also steel mill, textile factory, desalination plant and so on.

They are suspected to be locally discharged into river or sea with more than 40℃ of temperature in some nations.

Temporal and spatial influences of thermal discharge onto coastal zone depend on effluent rate as well as temperature difference. Numerical analysis has tried to predict the scope of environmental impact based on diffusion of density current. And lots of field surveys give the practical information to predict the scope. For example, the area of increasing more than 1℃ reach to 2 to 6 km in Japan[4]..

Impact of thermal pollution make a resultant damage to marine livings in coastal zone. Though various living things are dwelling in the wide temperature range of - 2℃ to 100℃ on the Earth, each living things can be survived in narrow temperature range to endure in the place. They can not survive under lower limit or over upper limit of fatal temperature of inherited by DNA. Especially, cold stenotherms with less than 10□ could be more sensitive against the severer fluctuation of temperature difference[2].

Many species in tidal zone have possessed surviving strategy and physiological adaptation. As the results, some livings can endure over tolerable change of temperature; others can not overcome the impact or migrate to other eco-system at last. Sustainable efforts are necessary to lessen temperature difference between coastal water and discharge from plants to preserve coastal eco-system.

IV. COMBINATION OF OTEC SYSTEM AND POWER-PLANT

Power plants with Rankine cycle generation system have to boil water as the working fluid by using nuclear or fossil fuel, and the steam of high pressure and temperature rotate the steam turbine with attracted by condenser of successive cooling water. As thermal energy can be transferred into electricity in the process, about double amount of the transferred heat emit to surrounding environment. Almost waste heats transfer into cooling water, the resultant discharge get warmer 10℃ in average than raw seawater for cooling.

Closed cycle OTEC system has also similar cycle as power-plant except working fluid as ammonia. Working fluid can be evaporated by gaining heat from warm seawater by heat exchanger to rotate turbine generator, and it must be condensed by rejecting heat by heat exchanger. Though OTEC can be operated in lower temperature difference between heat source and sink, more than 17 or 20℃is recommendable for regular production. Generation of electricity is declined about 10% with decrease of 1℃ from feasible temperature difference[4].

Enough heat source is essential to stabilize the operation of OTEC, it become an obstacle of launching OTEC projects in the low latitude countries. To overcome the poor difference of water temperature during winter season, power-plant discharge can become one of useful heat source. This implies that power-plant may also have a merit of decreasing thermal pollution.

To use the thermal discharge for OTEC, all we have to do is connecting outlet from condenser of power-plant with inlet of evaporator of OTEC system as shown in Fig. 5. As the lowest temperature of the discharge is about 22 to 25℃ in Korean, deep seawater of 2℃ is required to sustain enough temperature difference. The scale of OTEC plant depends on the available amount of thermal discharge and deep seawater intake.

Direct discharge from evaporator and condenser of OTEC plant may be colder than natural coastal water[6]. If every discharge from power-plant and OTEC plant is dumped into separated diffusers, cold and warm ponds may be made locally in the coastal zone. However, these discharges can be mixed to avoid such phenomena, and controlled to make optimal temperature.

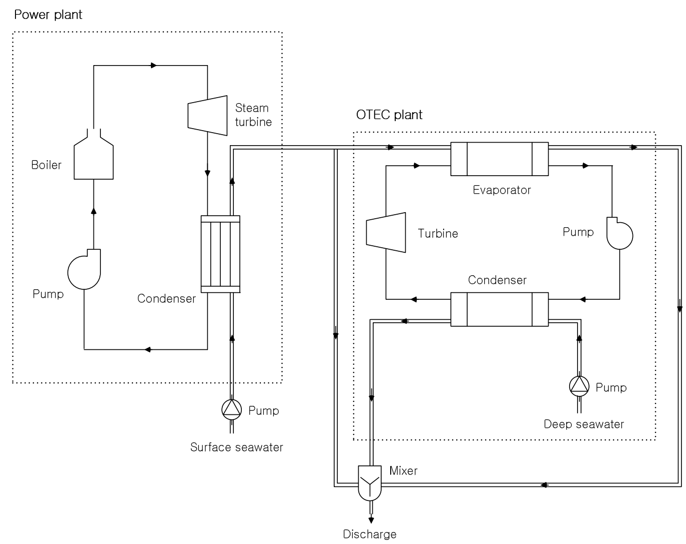

Figure. 5. Combined system of OTEC and power plants.

V. VARIATION OF DISCHARGE FROM COMBINED OTEC AND POWER PLANTS

To optimize the environment enhancement of combined OTEC system plus power-plant, the size of OTEC plant have to be chosen by considering resultant temperature of mixing.

This study analyzes the change of temperature difference by combined discharge between closed cycle OTEC plants with 1 to 3MW mean power and a 325MW coal fired power-plant. The objective power-plant in the eastern coast of Korea intakes 676,000 m^3/day of surface seawater, and discharges same amount with increasing temperature of 10℃. The resultant discharges were simulated by mixing of condensing and evaporating waters under OTEC operation and extraneous discharge from power-plant.

The annual temperature variation of the objective power-plant discharge is shown as in Fig. 6. The averaged annual temperature of the discharge from power-plant was 26.6℃. Mixed discharge of the combined plants become less temperature difference with coastal water as shown in Fig. 6. If the combined plant with 1MW OTEC plant operates, the resultant temperature of combined discharge decrease to 23.7 ℃ in average. If 3MW OTEC plant is applied, the averaged temperature is decreased to 18.8℃. It becomes closer to the mean temperature of natural coastal water.

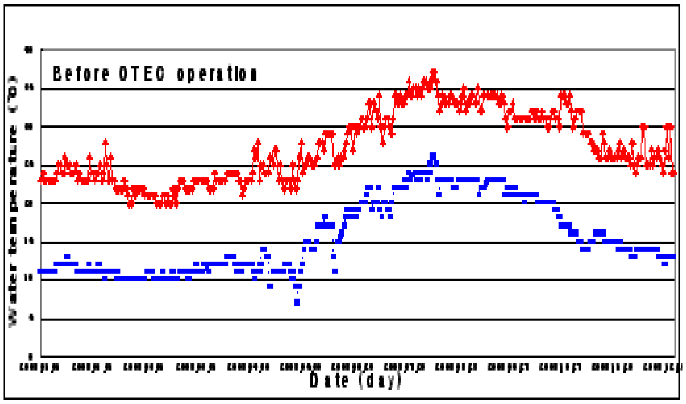

Fig. 7. Temperature variation of power-plant discharge and intake

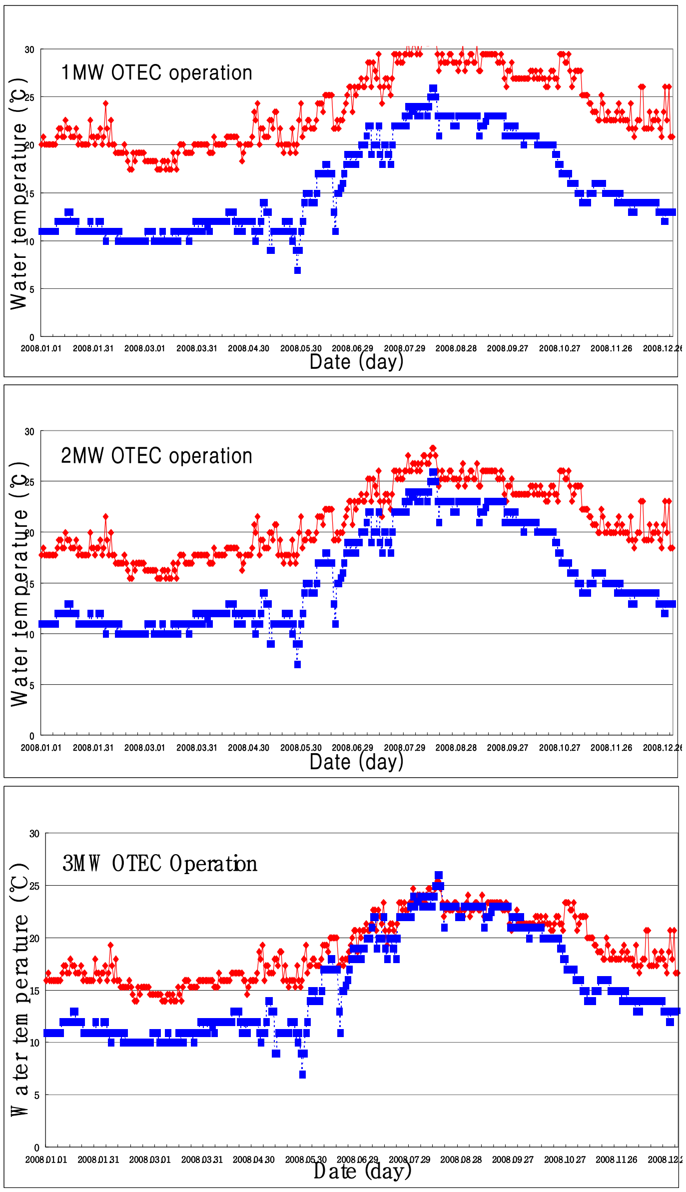

Figure 8. Temperature variation of discharge from the combined plant and natural coastal water.

VI. Conclusion

This study deals with the possibility of adaptation of OTEC system to power-plant to reduce the environmental impact of warm discharge. The objective OTEC plant was selected as closed cycle system to combine with power-plant. Deep seawater was used for condenser of OTEC plant, and warm discharge from power-plant was flowed into to evaporator of OTEC plant.

As a result of operating 1 MW OTEC plant combined to power-plant, the temperature difference of the resultant discharge from coastal water was reduced from 10 ℃ to 7.5℃. If 2 or 3 plants of 1MW OTEC can be applied, the temperature difference can be reduced to 5℃ or 2℃. These smaller differences between discharge and coastal water could be supposed to mitigate the impact of thermal discharge onto coastal eco-system.

It is clear that these methods have multiple effects of reducing carbon dioxide emissions and thermal pollution as well as of producing renewable energy[7]. 1MW OTEC plant can produce 5,694,000 kWh of electricity and reduce 4200 tons of carbon dioxide emissions[8]. And the effects would be proportionally magnified if the plants are added or expanded.

Acknowledgment

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