Review On Ocean Thermal Energy Conversion & Systems

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Abstract

This paper highlights the innovations and new technologies introduced to Ocean Thermal Energy Conversion (OTEC). The various technologies that have been reviewed include ammonia-water based thermal energy conversion system, dual-used open and closed-cycle ocean thermal energy conversion system by the use of solar preheating and solar-boosted OTEC.

Keywords — ocean, energy, thermal, desalination.

INTRODUCTION

Ocean Thermal Energy Conversion technology, also called OTEC, utilises the thermal gradient among the hot water at surface and cold water deep below the ocean to either operate any engine or use the available heat energy for other useful purposes. The arrangement may be open type, closed type or hybrid type. In open-cycle system the waster at the surface of the sea get heated from solar radiations and has been used as working fluid. A steam has been prepared in an evaporator. The high temperature and pressure steam then enters the turbine so that the power will be generated. The condensation of the steam is takes place after the power generation.

The closed system is similar to the open-cycle with the exception that the working fluid is a refrigerant [5]. The warm sea water is used to evaporate the refrigerant in the heat exchanger known as generator and it then expands inside the turbine to produce power. The thermal efficiency of the open system is generally less than the closed system, though they are working at same temperatures. This is because the open cycle system requires vacuum in the system for the flash evaporator to produce steam and the equipment used to maintain vacuum increases power consumption.
The merits of the open as well as closed system are used to make a hybrid system. It uses the left over thermal energy of the closed cycle after power generation to desalinate the water, although its desalination rate is much less than the open cycle.

**Ammonia-Water Based System**

Han Yuan and Lu Wang (2013) [2] conducted experimental investigation on ammonia-water based OTEC system. The effect of increase and decrease in the temperature of working fluid is analyzed under various operating conditions. The effect of the flow rate on the system is also examined. It is reported that thermal efficiency was most affected by the heating source temperature. The cooling source temperature also plays a vital role in thermal efficiency. Whereas, discharge of the fluid negligible impact on thermal efficiency.

![Fig. 1. Effect of the heat source temperature on thermal efficiency [2].](image)

It was observed from results that with increase in heating source temperature the thermal efficiency increased. The thermal efficiency of the system was increased from 0.3-0.75% at temperature of 40 °C. However, at the temperature of 35 and 30°C it was increased to 0.08-0.35% and 0.27-0% respectively. Further study of test data shows that thermal efficiency was also a function of cooling source temperature. The performance of the cycle increased with decrease in cooling source temperature.

**Dual Use Open Cycle OTEC System**

Albert S. Kim and HyeonJu Kim (2015) [1] observed the effect of a multiple condenser open-cycle OTEC system for dual purpose i.e. electric power generation and water desalination. Data analysis was done for generation of electricity and detoxification of seawater. The flow rates to the steam turbine was varied. Various parameters like warm and cold water temperatures, flow rates, evaporator pressure, were scrutinized to determine the optimal operation conditions for different OC-OTEC plant scales. In the power generation $K_{tb}=1.0$ i.e. all the produced steam is utilized in the turbine. During the purification of the water the factor was found as $K_{tb}=0.0$. This means that in the condenser all the steam is converted to the liquid phase. This desalination process is identical to the multi stage distillation process.
Fig. 2. The variation of the power generation with the cold water temperature at different temperatures of warm water [1].

As shown in the Fig. 2, it was observed that the rate of flow of the cold water and power generation is a function of temperature of warm water temperature $T_{in}$. For this test the generated steam was supplied into the turbine and condenser at 50%. They showed similar non linear increasing trends as shown in the graphs above. The experiment was conducted and the data was analyzed to provide design criteria for optimal utilization of dual-use Open Cycle OTEC system. Effects were investigated with respect to steam flow fractions and cold water flow rates for 1000 kW plant.

The change in the steam pressure results in change in power production, the rates of desalination of water and flow rates of the cold water. With increase in pressure, the driving factor for warm water evaporation decreases because of the stable temperature and gradient of low concentration will reaches the warm water inlet temperature. This leads to reduced steam generation rate and as a result the required cold water intake to condense the steam also decreases.
Fig. 3. Dependence of relative desalination [g/kg], with respect to $K_{tb}$, [1].

The above data in Fig. 3 showed the relative desalination rate with respect to steam flow fraction to turbine. It was observed that as the steam flow fraction to turbine was increased the relative desalination rate decreased in both the cases i.e., 207 kW and 1000kW systems. The inlet of the cold water and power production showed variation with respect to steam fraction through turbine $K_{tb}$. Though small values of $K_{tb}$ do not give any practical knowledge but it was considered necessary to understand the entire system response to the variations in steam fraction through turbine. It was evident from data that as $K_{tb}$ increased from 0.0 to 1.0 the cold water intake increased which showed that power production required additional cold water intake as compared to desalination process for the same steam rate. Also the cold water flow rate of the 1000kW system was higher than the 207kW system as was expected. It was also observed that the comparative power production and the desalination discharge of the larger scale system were marginally higher than the small-scale system.

The relative power production rates as shown in Fig.4 were observed to show a extreme value as compared to the steam flow fraction to the turbine. From the given data the value of steam flow fraction for best performance was calculated which turned out to be $K_{tb}= 0.68415$. 
The comparative power generation rate had extreme value for the calculated value of steam fraction through turbine. It was worth noting that the non-linear behavior of inlet rate of cold water as compared to the warm water intake, steam fraction $K_{tb}$ and system pressure is the main characteristic to understand the behaviour of the dual use open cycle OTEC system.

**CLOSED-CYCLE OTEC ARRANGEMENT USING SOLAR RADIATIONS**

Hakan Aydin and Hyeon-Ju Kim (2014) [3] observed the performance of a Closed Cycle OTEC system with solar thermal collectors installed as pre-heaters and super heaters. The analysis was numerically simulated on a simple OTEC setup designed to generate 100 kW power. Since the thermal efficiency of the heat engine depends upon the heating source temperature, solar thermal collectors were used to further preheat the warm surface water. It was observed that power output increased marginally with increase in solar power absorption at the pre-heater till 3000 kW, as shown in Fig 5, and beyond that the increase was substantial. Since the turbine speed was kept constant, the solar pre heating increased the enthalpy of working fluid at entry to turbine. Thus, the discharge of warm water was reduced whereas the flow rate of working fluid was increased to maintain the energy balance. The overall cycle efficiency was increased by 4 %.

![Fig. 4 The variation in power production rate [kJ/kg] with $K_{tb}$, [1].](image)
Any further solar power absorption by the solar pre heater would result in wastage of heat instead of being utilized in the evaporator by the working fluid which is not desirable. Fig. 6 depicts the reduction in warm water flow rate till 3000 kW of solar power absorption. The temperature increase in pre heater is balanced by this decrease in flow rate of warm water in order to provide the same amount of energy to turbine so as to operate it at the predetermined point. The increased power output was due to increased working fluid flowrate.

However, any further pre-heating resulted in an increase in the temperature of warm water at exit. This was observed beyond the solar power absorption of 8500 kW. This led to wastage of the absorbed solar energy. Further simulation tests for superheating showed that the power generation increased by 25% with increased solar power absorption. This was observed primarily due to 3% increase in thermal efficiency as compared to 1.9% for the previous pre heating test, thus emphasizing that solar superheating generated higher useful net power in comparison. The overall cycle efficiency was increased by 5%.
Fig. 7. The variation of thermal and cycle efficiency of system with solar absorption. [3].

The Fig. 7 shows that there is a decrease in net thermal efficiency which signifies that absorbed solar energy was not used efficiently although the working cycle showed a 4% increase in cycle efficiency and as a result increased work output. The increased power consumption of the pump for working fluid was balanced by the increased power by solar pre heater.

Fig. 8. The percentage change in the net thermal and cycle efficiency with solar absorption. [3].

The Fig. 8 shows the results of superheating of fluid with solar energy. This required solar thermal collector as compared to the preheating system because both the specific heat and flow rate of the working fluid were much less than that of surface water. This system showed 25% increment in the power generation and thermal efficiency is increased to 3% which signified that superheating generated more useful power than pre heating by solar energy. The test results proved that solar thermal preheating and superheating both showed a potential increase of 20-25% in power output. Since superheating of working fluid required less solar collector area as compared to the solar heating of surface water therefore superheating should be considered a better option.
SOLAR-BOOSTED OCEAN THERMAL ENERGY CONVERSION SYSTEM

According to Noboru Yamada and Akira Hoshi (2008) [4], a solar boosted OTEC system could potentially generate more power as compared to the conventional OTEC system. Performance simulation was done for a 100kW solar boosted plant with first order modeling under ambient conditions. The closed cycle is generally based on the Rankine cycle, its efficiency is dependent on the temperature difference between the evaporator and condenser which further depend upon the warm water and cold water temperatures respectively. For a standard OTEC plant this temperature difference is usually between 15°C to 20°C. If this temperature difference could be increased by solar heating then the cycle efficiency could also increase.

Fig. 9. The relation between operating temperature range and theoretical thermal efficiency [4].

The Fig. 9 shows the variation of thermal efficiency of Rankine cycle as function of the temperature difference $\Delta T$ for standard OTEC system and for the Solar boosted system (SOTEC). It was expected that the temperature range could be increased by another 20°C by utilizing solar energy. The required effective area for achieving this 20°C temperature for different types of solar collectors is given in Fig. 10.

Fig. 10. Effective area required for 100-kWe SOTEC plant atKumejima island,[4].

The simulation results indicated that the solar boosted OTEC can increase efficiency over standard system by means of low cost solar collectors.
Fig. 11. Rankine-cycle efficiency hnet of SOTEC plant and conventional OTEC plant at Kumejima island [4].

Fig. 11 shows the hourly variation in efficiencies for a 20°C temperature increase using a flat plate solar collector with effective area of 5000 m². It was evident from the data that the enhancement in the thermal efficiency was substantially higher than the standard OTEC system.

CONCLUSION

The literatures reviewed while preparing this term paper explain the new and upcoming technologies in the field of Ocean Thermal Energy Conversion and Systems. Different systems utilizing open cycle, closed cycle and hybrid cycles were explained along with the latest technologies being employed to increase the efficiency of the system which primarily focused on integrating the solar thermal energy absorption systems with the OTEC. This is because Ocean Thermal Energy is considered the most important renewable energy source as it is available for 24 hours a day 365 days a year, unlike the solar and wind energy sources which are not as consistent [5]. Also this source of energy remains largely untapped with expected power capacity of 88,000 TWH/year as per the reports of World Energy Council in 2000 without affecting the oceans thermal structure.

REFERENCES


