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Review of the applied mechanical problems in ocean thermal energy conversion

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ABSTRACT

Ocean thermal energy attracted significant attention for its large storage in the ocean. With the increasing exploitation of ocean thermal energy due to the development of technology, several devices were proposed, which can be categorized into the closed cycle, open cycle and hybrid cycle systems. Many researchers have focused on the evaluation of these systems in regard to the economic evaluation, power and efficiency evaluation, function evaluation and environmental impact evaluation. To analyze the performance of such device in the ocean environment, several fluid mechanics problems need to be considered, including steam turbine specific for OTEC system, the wake induced by the long cold water pipe and the turbidity currents on the steep slope. The current work gives a review of these different systems, and presents the power and efficiency calculation formulas. The mechanical applications in the ocean thermal energy conversion (OTEC) system are then discussed.

1. Introduction

Ocean thermal energy conversion (OTEC) is a process using the ocean thermal power caused by the temperature differential between surface and deep seawater to generate the electricity. The exploration of the OTEC can date back to 19th century, Jacques Arse`ne d'Arsonval, a French scientist, first put forward a feasible scheme for setting up OTEC system in 1881, and his student Georges Claude built the first OTEC plant in 1930 [1]. However, this technology was not a favorable method to generate the power originally because of its high construction price and low energy conversion efficiency. After oil crises in the 1970s and the consciousness of the environmental protection, the OTEC system developed rapidly and several countries, principally in France, Japan and the United States, attached importance to exploit ocean thermal energy. Several experimental devices were also installed during this period. For example, the Tokyo Electric Power Company, a Japanese company, constructed one of their 100 kW ocean thermal energy converter in Nauru and embarked on the exploration of this technology [2]. India also started the OTEC program since the 1980s and tested an OTEC plant (1 MW) near Tamil Nadu in 2002 [3]. A United States company, Makai Ocean Engineering continued on the researches on the commercialization of OTEC since their first net-power producing plant in 1979 and recently designed a 100 kW demo plant in 2013 [4]. A 10 MW plant is under construction by a French company DCNS group and would deliver for usage by 2016 [5]. Furthermore, some countries also proposed projects to promote the researches on the power generation using thermal energy, such as Japanese National Sunshine Projects [6]. Due to the huge energy potential of OTEC, more and more countries like Philippine and Malaysia actively start investigating and developing the related energy conversion methods [7,8]. In 2013, the first International OTEC symposium was held in Honolulu, Hawaii, which strengthened the cooperation of ocean thermal energy studies and promoted the development of standards of ocean thermal energy standards [9].

1.1. Device design

The OTEC systems can be divided into two types according to the location of the plants [1,10]. The principal types of OTEC system include the land-based plant and floating platform, as shown in Fig. 1. In this section, a brief introduction of these two different OTEC systems is presented, and the thermodynamic principles are described with more details in Section 2.

The land-based devices (Fig. 2) are usually located in a tropical

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Nomenclature

A	cross-sectional area
B	body force
D	diameter
E	elastic modulus
F	surface force
f	friction factor
g	acceleration of gravity
h	enthalpy
I	moment of inertial
L	pipe length
m	quantity
P	pressure
V	velocity
W	power
CWP	cold water pipe
OSP	offshore solar pond
OTEC	ocean thermal energy conversion

Greek letters

α	ratio of liquid ammonia to mixture in evaporator
β	ratio of liquid ammonia to whole mixture
η	efficiency
ρ	density

Subscripts

a	circulating working fluid
c	condensing or condenser
cs	cold seawater
e	evaporating or evaporator
eo	outlet of the evaporator
g	generator
cp	circulating pump
sp	seawater pump
t	turbine
to	outlet of the turbine
wf	working fluid
ws	warm seawater
r	radial direction
θ	tangential direction
z	vertical direction

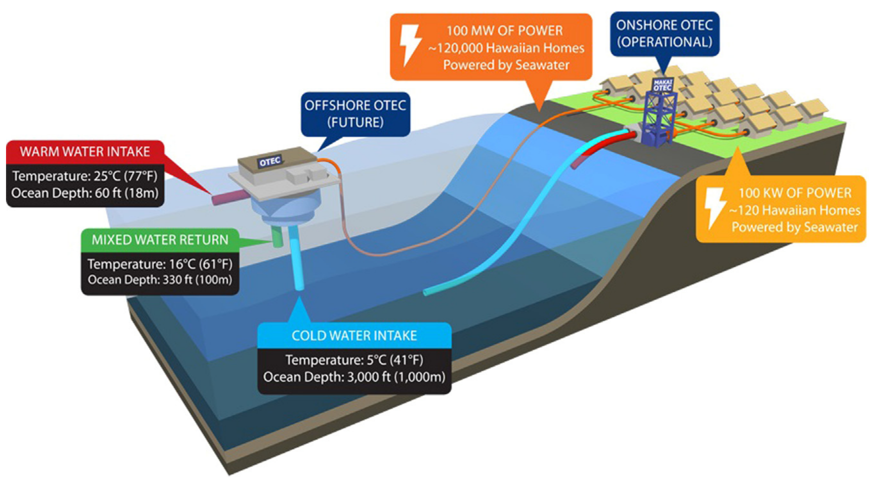

Fig. 1. The schematic diagram of the land-based and floating platform OTEC system [4].

coastal region with the steep seabed. Since these devices were constructed on the shore, the influence of climate on the plants is less significant than that on the offshore floating plants, which contributes to the reduction of the maintenance costs. Although the construction of the land-based plants is easy to implement, some challenges still exist during the operation. Earthquakes or eruptions would cause landslide and turbidity currents, which may damage the CWP laid on the seabed. Among the various developments, Natural Energy Laboratory of Hawaii Authority (NELHA), the foremost OTEC experimental equipment, was found in 1974 and cooperated with the University of Hawaii, Makai Ocean Engineering and US Navy successively [11].

The floating OTEC plants (Fig. 3) are usually located far from the coast and float on the surface of the water. The locations are carefully chosen to acquire sufficient temperature difference. As the severe weather (typhoon and tsunami) often occurs in tropical regions, the capability to operate stably in the enormous wind and wave should be taken into account during the design of the floating OTEC plants. Although floating OTEC system has many problems in the application, it has several successful examples. The famous Lockheed spar-type OTEC platform and the design proposal of an OTEC plant ship to generate the electricity and produce the ammonia are successful examples [12].

1.2. Previous studies on OTEC

To analyze the possibility of the commercial application, the economical efficiency of OTEC device is calculated in details [13–16]. Since the OTEC system is complex, many researchers investigated different aspects of the technology and some literature reviews were also published to summarize the achievements of these researches. The OTEC system can be understood generally from reference [17] and [18], which give a broad overview of the technology and the applications of OTEC. For example, Tanner [19] reviewed the applications of the OTEC technology apart from the power generation and identified the barriers to the commercialization. Cohen [20] also summarized the challenges and possibilities for commercializing of OTEC device. Wang et al. [21] reviewed the previous OTEC researches and discussed the problems in OTEC application in energy utilization, platform design and environmental impact. Vega [22] introduced the technologies of the OTEC system. After several experimental plants were built, researchers like Trimble and Owens [23] collected the performance data and described the practical application of the OTEC. To reach the maximum utilization of the thermal energy, Morse et al. [24] investigated the corrosion of the heat exchanger in OTEC caused by the