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Web Application for OTEC Simulator Using Double-stage Rankine Cycle *

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Abstract: In this research, a Web application for a simulator of an ocean thermal energy conversion (OTEC) plant with double-stage Rankine cycle is developed. A simple dynamic model of the OTEC plant with double-stage Rankine cycle which consists of steady state calculation of state variables based on mass balance and energy balance, and transient calculation of the heat exchanger dynamics is adopted for construction of the simulator. Performance indexes which are used for effective OTEC operation are also calculated in the simulator.

Keywords: Ocean thermal energy conversion (OTEC), double-stage Rankine cycle, dynamic simulation model, Web application.

1. INTRODUCTION

Energy and environmental problems are worldwide and various technologies are adopted in order to solve the problems. Usage of renewable energy such as wind power, photovoltaic power and geothermal power, is one of the solutions of the problems (Khaligh and Onar (2010)). Ocean thermal energy conversion (OTEC) is renewable energy which uses the temperature deference between the upper layers warm seawater and the deep layers cold seawater of the ocean to drive a generator connected to a turbine (Avery and Wu (1994)). The temperature of the warm seawater is about 20–30 [°C] and that of the cold seawater is about 4–10 [°C]. The temperature difference of seawater is very low and thermal efficiency of OTEC is rather small about 3–4 [%] compared with commercial thermal and nuclear power plants.

In order to improve the thermal efficiency of OTEC systems, a double-stage Ranking cycle is investigated (Morisaki and Ikegami (2014); Kusuda et al. (2015)). In cycle analysis and performance tests, the double-stage Rankine cycle gives improved in performance compared with a single-stage one.

Dynamic modeling of organic Ranking cycles which gives the dynamical behavior of the plant has been proposed (Wei et al. (2008); Quoilin et al. (2011)). However, a dynamic model for an OTEC plant with double-stage Rankine cycle has not been proposed and the simulator using the dynamic model has not also been developed.

In this research, a Web application for a simulator of an OTEC plant with double-stage Rankine cycle is developed. The simulator consists of a dynamic simulation model of double-stage Rankine cycle and GUI using HTML. The simulator gives the state variables and performance indexes of the OTEC plant with double-stage Rankine cycle. Only a Web browser with the Internet environment is required for usage of the simulator.

In the next session, OTEC with double-stage Rankine Cycle is presented. The dynamic simulation model is described in Section 3. Section 4 deals with the Web application of OTEC simulator. The proposed dynamic simulation model and the Web application are discussed in Section 5. Finally, Section 6 shows conclusion.

2. OTEC SYSTEM WITH DOUBLE-STAGE RANKINE CYCLE

A single-stage Rankine cycle system mainly consists of an evaporator, a turbine, a generator, a condenser and a working fluid pump, where the evaporator and condenser are employed as heat exchangers to absorb and release the heat energy, respectively (Johnston et.al. (1992)). The process of the single-stage Rankine cycle is that the working fluid pump takes working fluid from the condenser, raises its pressure isentropically to evaporator pressure and delivers it to the evaporator. Next, heat is added in the evaporator at constant pressure until the

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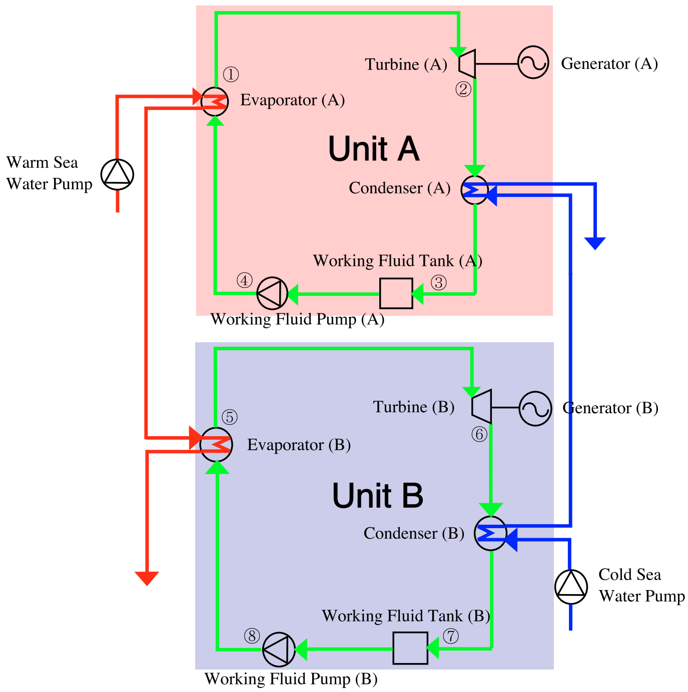

Fig. 1. Process flow diagram of double-stage Rankine cycle

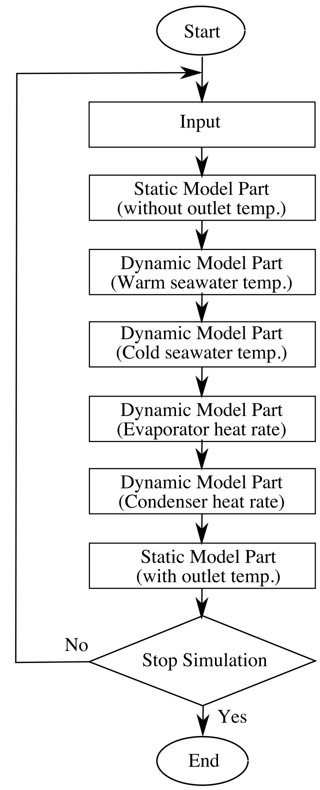

Fig. 2. Flow chart of dynamic model of OTEC with double-stage Rankine cycle

working fluid becomes saturated vapor. The vapor then expands isentropically through the turbine until it reaches condenser pressure. Finally, heat is removed and the vapor becomes a saturated liquid at the condenser discharge, where it is finally picked up once more by the working fluid pump.

Figure 1 shows the process flow diagram of the double-stage Rankine cycle. A double-stage Rankine cycle is a series connection of two independent Rankine cycles (Unit A and Unit B). In the double-stage Rankine cycle, warm seawater passes through the evaporator of Unit A and it flows directly to the evaporator of Unit B. Similarly, cold seawater passes through the condenser of Unit B and it flows directly to the condenser of Unit A. The double-stage Rankine cycle can improve in performance of the maximum power output compared with a single-stage Rankine cycle (Morisaki and Ikegami (2014)) and the performance has been tested by an experimental plant (Kusuda et al. (2015)).

3. SIMPLE DYNAMIC SIMULATION MODEL OF DOUBLE-STAGE RANKINE CYCLE

3.1 Outline of Simulation Model

The proposed simple dynamic simulation model of double-stage Rankine cycle is constructed with specifications of an OTEC plant and physical constants. The inputs of simulation model are temperatures and flow rates of warm and cold seawater and working fluids, and the outputs are state variables and performance indexes of the OTEC plant. In the OTEC plant, time delays will occur dominantly in heat transfer at heat exchangers of evaporators and condensers. Then, the time delays of heat transfer are included in the dynamic model. In steady state, the static relationships of energy balance and mass balance are fulfilled. Moreover, the performance indexes of the OTEC plant which are used for plant design and its effective operation are calculated.

The assumptions of the dynamic model are as follows;

(1) Working fluids at the outlet of the evaporators are the saturated vapor.
(2) Working fluids at the outlet of the condensers are the saturated liquid.
(3) Dynamics of temperatures and heat flow rates at the heat exchangers can be simply modeled by the lumped-parameter first-order system.
(4) No time delays of turbines, pipes and other equipment without heat exchangers exist.
(5) No loss and no dead time in equipment such as pipes exist.
(6) Turbines and working fluid pumps are isentropic, and evaporators and condensers are isobaric.

Figure 2 shows the flow chart of the proposed simple dynamic model of an OTEC system with double-stage Rankine cycle. The model is divided into two static models of with and without heat exchanger outlet seawater temperatures and four dynamic models of warm and cold seawater temperatures and heat flow rates of evaporators and condensers.

Table 1 shows the symbols and their meanings used in the dynamic model and Table 2 shows the specifications of the OTEC plant using double-stage Rankine cycle. Table 3 shows the physical constants used in the dynamic model.

The details of the proposed simple dynamic model are explained in the following sections.