Pilot test of OTEC-CC-MX-1kWe prototype plant

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I. KEYWORDS

OTEC, prototype, close cycle, pilot test, plant.

II. INTRODUCTION

Ocean Thermal Energy Conversion (OTEC, Ocean Thermal Energy Conversion) is a technology that uses the temperature difference between surface seawater and subsurface seawater (up to 1000 m) to produce electrical energy through the Rankine thermodynamic cycle [1]. Mexico has vast potential for OTEC development [2,3], for this reason, the development of OTEC plant prototypes is of great interest in order to contribute to demand energy supply and to reduce fossil fuels consumption for energy generation. With the support of the Mexican Centre for Renewable Energy of the Ocean (CEMIE-O, in Spanish), it was implemented and tested the Mexican closed-cycle OTEC prototype (OTEC-CC-MX-1kWe) to produce 1 kW of electricity at lab level (TRL-6). It is worth mentioning that this prototype was designed according to Mexican Caribbean Sea temperature conditions, and it is planned to function as a testing facility for OTEC development. Figure 1 presents the diagram of piping and Instrumentation of the OTEC-CC-MX-1kWe plant prototype.

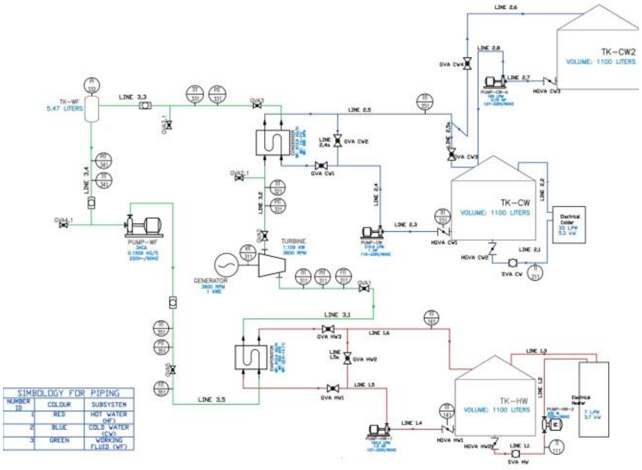

Fig. 1 Diagrama de tubería e instrumentación del prototipo

OTEC-CC-MX-1kWe is composed of three subsystems: the heating system, the cooling system, and the Rankine system. The heating system is provided with an electric heater to simulate the surface seawater temperature, whereas the cooling system is provided with a mini chiller to simulate the sub-surface seawater temperature. According to Mexican Caribbean Sea conditions, the mean annual temperature is 27°C and 7°C for surface and sub-surface seawater, respectively [5]. On the other hand, the main components of the Rankine system are two gasketed plate heat exchangers, a turbine, and a working-fluid pump. This system uses as working fluid the refrigerant R-152a, which was selected among 50 fluids due to its thermodynamic, safety, and toxicity properties [4]. In this system, the R-152a at compressed liquid state is transported by the pump to the evaporator, where the working fluid is evaporated into a saturated vapor state by warm water from the heating system. Then the vapor drives the turbine and the connected electrical generator to produce mechanical energy. The mixture vapor from the turbine is condensed into saturated liquid state in the condenser, and then the saturated liquid of the working fluid is transported by the pump to the evaporator to begin the cycle again.

III. PILOT TEST

According to the test protocol, it was performed the pilot test of the prototype. Temperature, pressure, and volumetric flow were measured and saved in real-time using analogic instrumentation and electronic sensors.

In Figure 2 is shown the temperature of R-152a at each line of the Rankine system. At lines 3,1 (TIT311); 3,2 (TIT321); and 3,5 (TIT351) was stabilised at 16:20:43 h. At the beginning of the pilot test, the temperature at line 3,3 (TIT331, at the outlet of the condenser) had a similar tendency as TIT351; however, this line has an increment of temperature during the experiment, from 10.63°C to 11.96°C, which, according to the plant design, it must stabilize at 12°C. During the pilot test, other unexpected temperature values were found, for example, it was noted that TIT331 and TIT341 exceed TIT351, which is not normal for this thermodynamic cycle. Using this data, some quality results establish that at the outlet of the condenser, the R-152a was at saturated vapor state, although through the sight glass installed at this line, it was observed liquid during all the pilot test. This behaviour is attributed to TIT331 sensor malfunction, therefore is required its re-calibration for future tests.

The pressure variations of each line during the pilot test are shown in Figure 3. It is evident that at line 3,5 (PIT351), where the working fluid is pumped, the higher-pressure values are found. After passing through the evaporator, the pressure of the working fluid decrease to the PIT311 value. The difference between PIT311 and PIT321, caused by the energy exchange in the turbine, is the value expected according to the plant design.

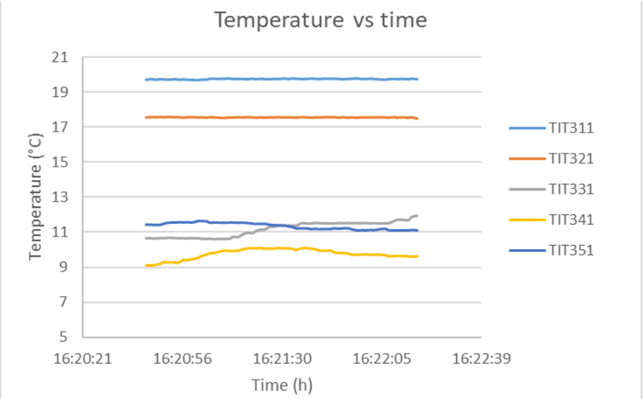

Figure 2. Temperature vs time

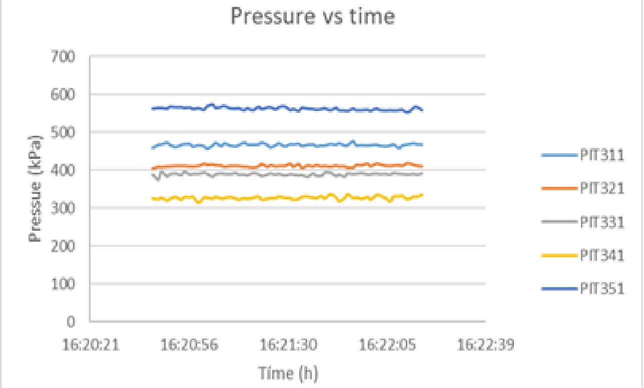

Figure 3. Pressure vs time

In Figure 2 and Figure 3 are observed that the temperature and pressure for most of the lines remain steady from 16:20:43 h to 16:22:17 h. Therefore, this range was selected to evaluate enthalpy, heat transfer in the evaporator and in the condenser, pump work, turbine work, and power generated. The thermodynamic properties were obtained in the EES program, as well the phase of the fluid for each line was contrasted to the design condition.

Turbine power was evaluated using the enthalpy difference between line 3,1 and line 3,2, multiplying by the mass flow of the working fluid. In Figure 4 is shown the maximum (563.35 W) and the minimum (232.64 W) turbine power during the pilot test.

IV. CONCLUSIONS

The OTEC-CC-MX-1kWe prototype is the first OTEC prototype in Latin America, and it was implemented at the Ocean Energy Laboratory of Universidad del Caribe.

The pilot test was performed, its results were satisfactory regarding the expected thermodynamic performance; however, the temperature sensors must be calibrated in future tests.

The OTEC-CC-MX-1kWe prototype is considered a testing facility, due to it allows the testing of different components, such as working fluid, pump, turbine. In this sense, different configurations of OTEC plants can be carried out and evaluated.

It is worth mentioning that is required to test the power generation of this prototype using the *ad-hoc* turbine design, to prove the kW of electrical energy produced and the drop pressure at the turbine (~125 kPa). This last one will allow line 3,3 to remain steady at 12°C, and therefore a positive total net power will be obtained in the thermodynamic evaluations.

An experimental design is being carried out to continue testing the OTEC prototype for improving the results and knowing its operational limits.

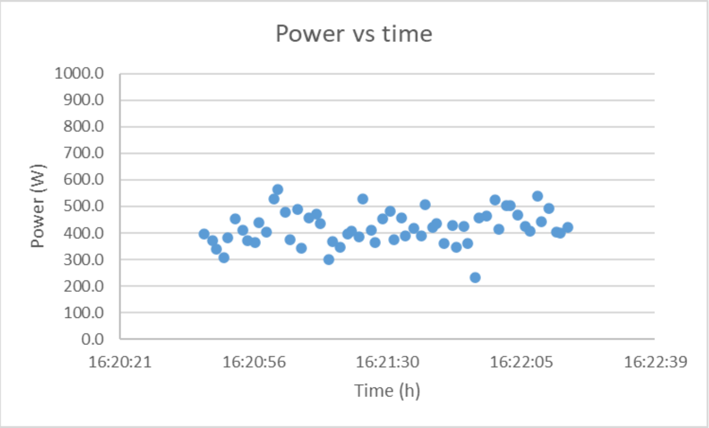

Figure 4. Power vs time

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