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colour inside

Marine energy – Wave, tidal, and other water current converters – Part 20: Design and analysis of an Ocean Thermal Energy Conversion (OTEC) plant – General guidance

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a Technical Specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specification are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62600-20, which is a Technical Specification, has been prepared by IEC technical committee 114: Marine energy - Wave, tidal and other water current converters.

The text of this Technical Specification is based on the following documents:

Draft TS	Report on voting
114/286/DTS	114/299A/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

A list of all parts in the IEC 62600 series, published under the general title *Marine energy - Wave, tidal and other water current converters*, can be found on the IEC website.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Seventy percent of the Earth's surface is ocean. Most solar energy striking the ocean is absorbed within the upper 100 m and is retained as thermal energy. Expanding slightly as it warms the surface seawater layer is reheated by additional sunlight resulting in temperatures often exceeding 25 °C in tropical latitudes. Deep seawater is much cooler, typically, about 4-5 °C at depths varying from 800 m to 1 000 m, as shown in Figure 1. This deep cold water is replenished from the polar regions by the thermohaline ocean circulation. From the temperature difference that exists between these upper and deep layers of the ocean, significant quantities of energy can be sustainably extracted by a process called Ocean Thermal Energy Conversion, OTEC.

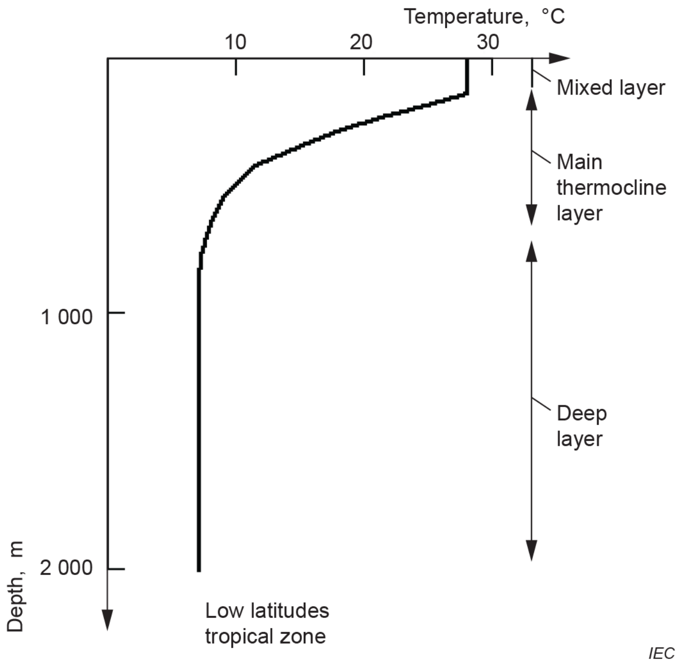

Figure 1 – Tropical ocean temperature-depth profile

The temperature difference between the ocean layers in the tropics changes very little during daily or even yearly cycles and shows a moderate and predictable seasonal variation. This steadiness creates an attractive characteristic in that OTEC can generate non-intermittent (sometimes referred to as 'base-load') power. Due to the relative simplicity of the process, OTEC is expected to have a very high capacity factor compared to most other forms or renewable energy. Capacity Factor is the ratio of actual electrical energy output over a given period of time, relative to the maximum possible electrical energy output over the same amount of time. The maximum possible energy output of a given installation assumes its continuous operation at full nameplate capacity over the relevant period of time. OTEC power output reliability and predictability is appealing when compared to the intermittency and hence low capacity factor of most renewable energy sources.

a) Working principle

OTEC converts a sustainable, low-grade heat source, ocean thermal energy, into electricity by applying a thermodynamic cycle. The theoretical maximum thermal conversion efficiency is determined by the Carnot cycle, where absolute ocean temperatures are applied in Kelvin. An example of the Carnot efficiency with a hot source of 27 °C and a cold source of 4 °C is:

$$\eta\_Carnot = 1 - T\_cold/T\_hot = 1-(4+273,15)/(27+273,15) = 7,66\ \%$$

This efficiency assumes that the conversion is done by an ideal, reversible heat engine. In practice, the actual heat transfer is irreversible due to temperature differences in the heat exchangers and other factors. These heat transfer losses and the actual performance of the turbine and generator shall be accounted for when calculating the actual efficiency. The non-ideal, actual efficiency would thus be in the range of 3 % to 4 %.

The OTEC process can be configured with different cycles: open, closed and hybrid. The choice of which system will be optimum will normally be based on site characteristics, such as local power and fresh water demand.

b) Closed cycle

Closed-cycle OTEC systems are based upon the Rankine thermodynamic cycle and use a refrigerant-type process working fluid, contained within a closed piping system. Liquid working fluid is pumped into an evaporator heat exchanger where heat from the warm seawater causes the working fluid to vaporise. This vapour is piped to a turbine where its enthalpic energy drives a turbine-generator. The turbine’s vapour exhausts to a condenser heat exchanger, where it condenses to a liquid by the cooling effect of the cold seawater. The liquid working fluid then drains to the working fluid pump, completing the cycle. Major components and flows of a Closed Cycle OTEC plant are illustrated in Figure 1 and Figure 2. Design considerations associated with these components will be discussed in Clause 5.

Within the evaporator, the warm seawater transfers its heat to the boiling working fluid, becoming less warm. Similarly, heat from the condensing vapour causes the cold deep seawater passing through the condenser to become less cold. The heat flow from warm water is 3 % to 6 % larger than the heat flow into the cold water. This difference is the energy usefully extracted by the turbine or lost due to friction.

The working fluid will have fluid properties that vary with the specific type used, such as R717 (anhydrous ammonia), R32, R134a or others. The evaporation and condensation properties and heat exchanger design performance should normally be selected to attain optimum efficiency for a particular working fluid. Within the process system, the highest pressure occurs at the working fluid pump outlet, the lowest pressure occurs in the condenser and the most significant pressure drop will take place within the turbine.

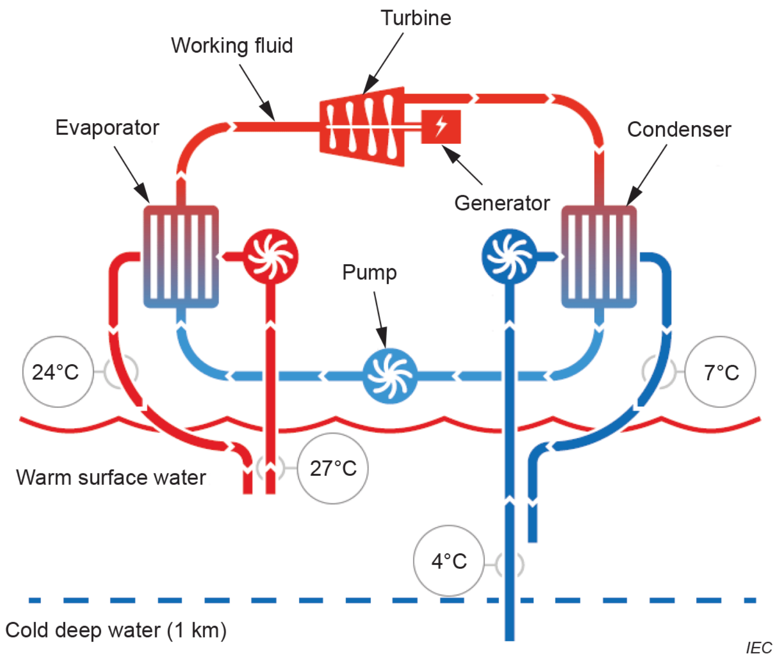

Figure 2 – Working principle of closed cycle ocean thermal energy conversion [2][1]

[1] Numbers in square brackets refer to the Bibliography.

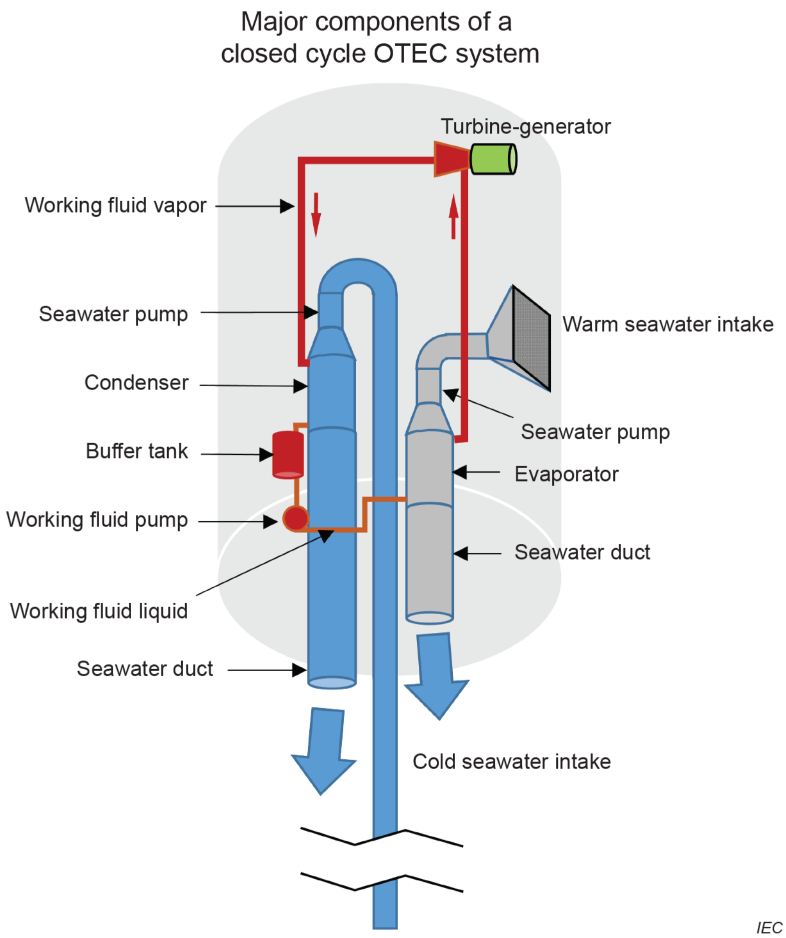

Figure 3 – Major power cycle components of a closed cycle OTEC plant

c) Open cycle

Open-cycle OTEC uses a vacuum process to exploit the different boiling pressures of warm and cold seawater. The working fluid is used only once and is continually replenished, hence the term "open" cycle. The process is as follows: Warm seawater enters a large evaporation chamber at approximately 96 % vacuum, where a small fraction of the seawater vaporizes to low pressure steam and the remaining seawater supplies the needed heat of vaporization. The cooled warm seawater is pumped from the evaporator. The low-pressure steam passes through a mist separator, drives a low pressure turbine and exhausts into the condensing chamber, which is maintained at approximately 98 % vacuum. The steam condenses directly onto cold seawater droplets within the condenser chamber and the slightly diluted cool seawater mixture is pumped from the condenser. Continuously-running vacuum compressors maintain the chamber vacuum by removing dissolved air and other trace gases that enter with the seawater flows.

Alternately, a large condensing surface heat exchanger can segregate the steam from the cold seawater, yielding quantities of fresh water suitable for drinking water or irrigation. Thus open cycle OTEC can be configured to produce both electricity and fresh water.

Both closed cycle and open cycle OTEC use the Rankine thermodynamic cycle. The primary difference is that open cycle systems use large vacuum chambers and a very high-volume low pressure steam turbine, whereas closed cycle uses heat exchangers, a smaller turbine and a working fluid pump. A schematic diagram of the open cycle OTEC system is given in Figure 4

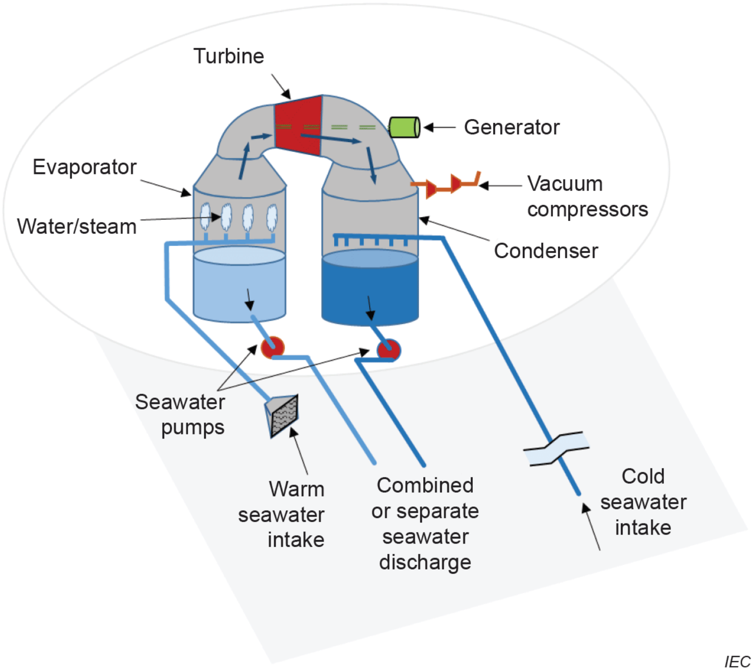

Figure 4 – Open cycle OTEC system

d) Hybrid cycle

A hybrid cycle combines features of both the closed-cycle and open-cycle systems to yield both electricity and desalinated water. Heat exchangers, vacuum chambers and other components may be arranged in numerous stages to extract additional thermal value from the "used" warm and cold seawater flows.

MARINE ENERGY – WAVE, TIDAL, AND OTHER WATER CURRENT CONVERTERS –

Part 20: Design and analysis of an Ocean Thermal Energy Conversion (OTEC) plant – General guidance

1 Scope

This part of IEC 62600 establishes general principles for design assessment of OTEC plants. The goal is to describe the design and assessment requirements of OTEC plants used for stable power generation under various conditions. This electricity may be used for utility supply or production of other energy carriers. The intended audience is developers, engineers, bankers, venture capitalists, entrepreneurs, finance authorities and regulators.

This document is applicable to land-based (i.e. onshore), shelf-mounted (i.e. nearshore seabed mounted) and floating OTEC systems. For land-based systems the scope of this document ends at the main power export cable suitable for connection to the grid. For shelf-mounted and floating systems, the scope of this document normally ends at the main power export cable where it connects to the electrical grid.

This document is general and focuses on the OTEC specific or unique components of the power plant, particularly the marine aspects of the warm and cold water intake systems. Other established standards are referenced to address common components between the OTEC system and other types of power plants and floating, deep water oil and gas production vessels, such as FPSOs and FLNG systems. Relevant standards are listed within this document as appropriate.

The flow diagram, shown in Figure 5, illustrates the main design process associated with floating, shelf-mounted or land-based OTEC systems.

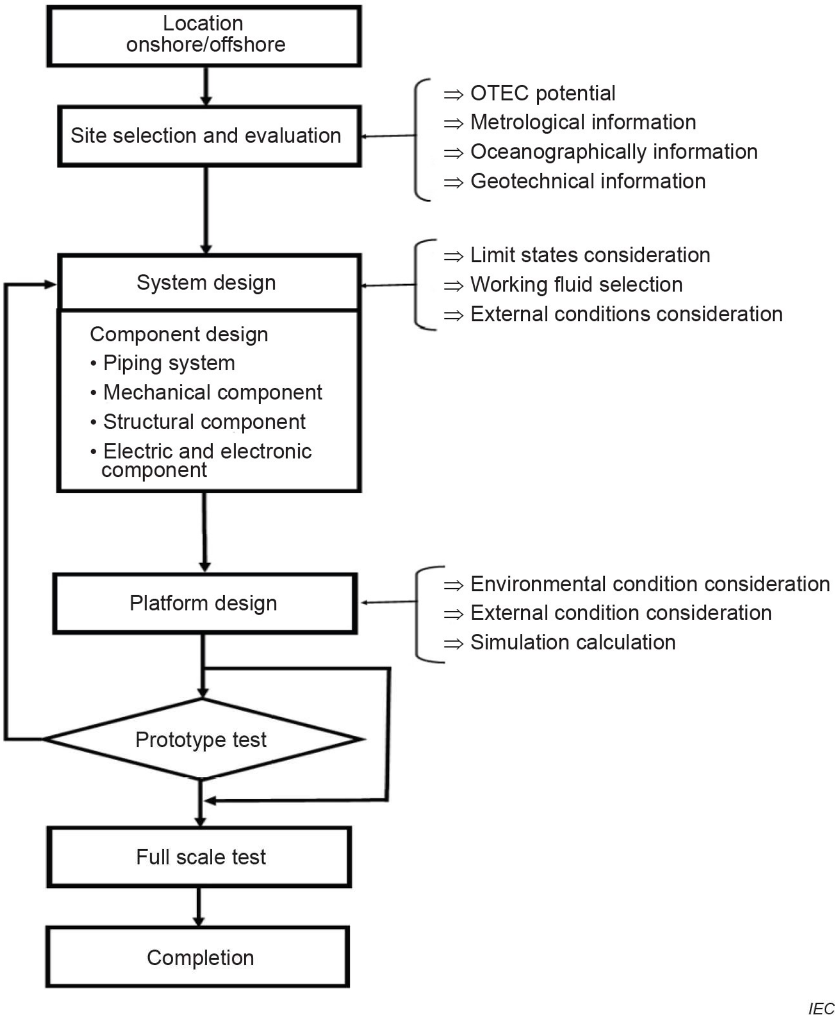

Figure 5 – Example of a typical process for developing and testing an OTEC system (land-based and floating)

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60079-0:2017, *Explosive atmospheres – Part 0: Equipment – General requirements*

IEC TS 62600-1, Marine energy – Wave, tidal and other water current converters – Part 1: Terminology

ISO 13628-5: 2009, Petroleum and natural gas industries – Design and operation of subsea production systems – Part 5: Subsea umbilicals

ISO 13628-11: 2007, Petroleum and natural gas industries – Design and operation of subsea production systems – Part 11: Flexible pipe systems for subsea and marine applications

ISO 19900, *Petroleum and natural gas industries – General requirements for offshore structures*

ISO 19901 (all parts): *Petroleum and natural gas industries – Specific requirements for offshore structures*

ISO 19901-1, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating considerations*

ISO 19901-7:2013*, Petroleum and natural gas industries – Specific requirements for offshore structures – Part 7: Station keeping systems for floating offshore structures and mobile offshore units*

ISO 19902, *Petroleum and natural gas industries – Fixed steel offshore structures*

ISO 19903, *Petroleum and natural gas industries – Fixed concrete offshore structures*

ISO 19905 (all parts), *Petroleum and natural gas industries – Mobile offshore units – Jackups*

ISO 19906, *Petroleum and natural gas industries – Arctic offshore structures*

ISO 21650, *Actions from waves and currents on coastal structures*