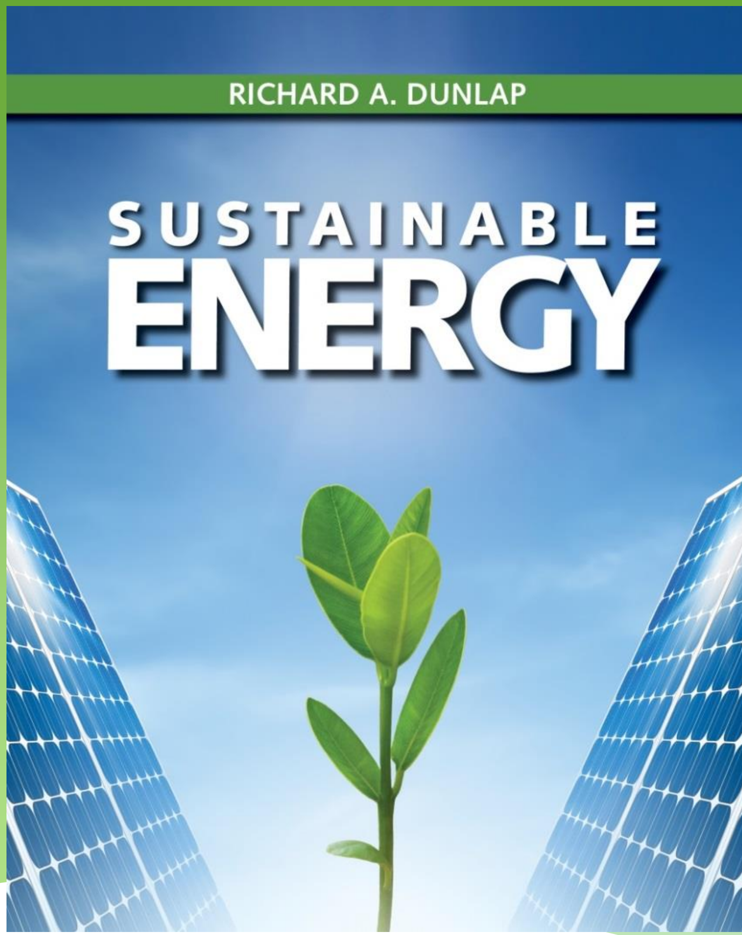
Sustainable Energy



Chapter 12

- Wave Energy

CENGAGE Learning

Learning Objectives

- The availability of wave energy worldwide.
- The relationship between wave properties and energy.
- The types of wave energy devices.
- The design of oscillating water columns and the properties of the Wells turbine.
- The use of floating and pitching devices for wave energy generation.
- The use of wave-focusing devices.

Wave power at different locations worldwide

Active wave energy development in Scotland, Portugal, Australia, Hawaii

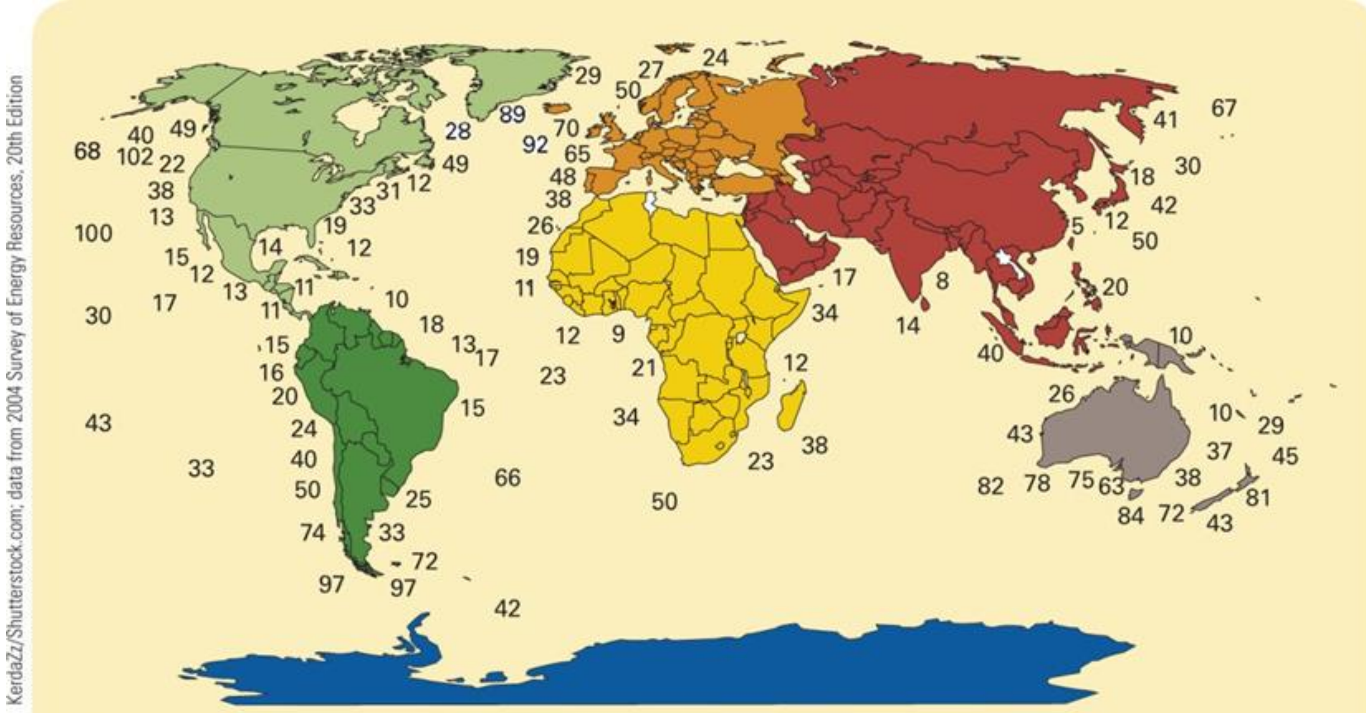


Figure 12.1: Wave power at various locations. Powers are average annual values in kW/m of wave front.

Analysis of energy associated with wave

Energy is both kinetic due to movement of water and potential due to geometry of water surface

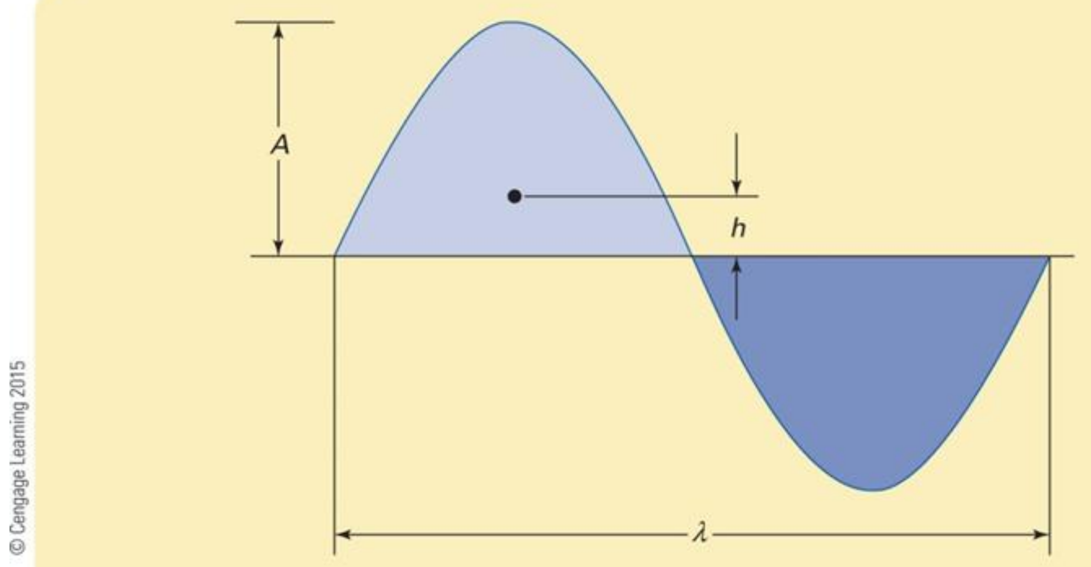


Figure 12.2: Cross section of a wave on the surface of the ocean.

Calculation of potential wave energy

The mass per unit length of half a sinusoid is

$$\frac{m}{l} = \frac{\rho A \lambda}{\pi} \qquad (12.1)$$

The height of the center of gravity above the surface

$$h = \frac{\pi A}{8} \qquad (12.2)$$

The potential energy per unit length is

$$\frac{E}{l} = \frac{m}{l} g \Delta h = \left(\frac{\rho A \lambda g}{\pi}\right)\left(\frac{\pi A}{4}\right) = \frac{1}{4}\rho A^2 \lambda g \qquad (12.3)$$

Total wave energy

It can be shown the wave's kinetic energy is equal to its potential energy, so the total wave energy will be

$$\frac{E}{l} = \frac{A^2 \lambda \rho g}{2} \qquad (12.4)$$

Wave power

The wavelength of a wave is related to its period by

$$\lambda = \frac{gT^2}{2\pi} \qquad (12.5)$$

Thus the energy per unit length is

$$\frac{E}{l} = \frac{A^2 g^2 \rho T^2}{4\pi} \qquad (12.6)$$

and the power per unit length
(as a function of crest to trough height, *H*=2*A*) is

$$\frac{P}{l} = \frac{H^2 g^2 \rho T}{16\pi} \qquad (12.8)$$

Classification of wave power devices

Several different designs of wave power devices have been utilized

- Oscillating water columns
- Floating and pitching devices
- Wave-focusing devices

Oscillating water column

Onshore or near shore device

Figure 12.4: Oscillating water column developed by Energetech in Australia that is anchored near shore, rated at 500 kW.

Schematic of oscillating water column

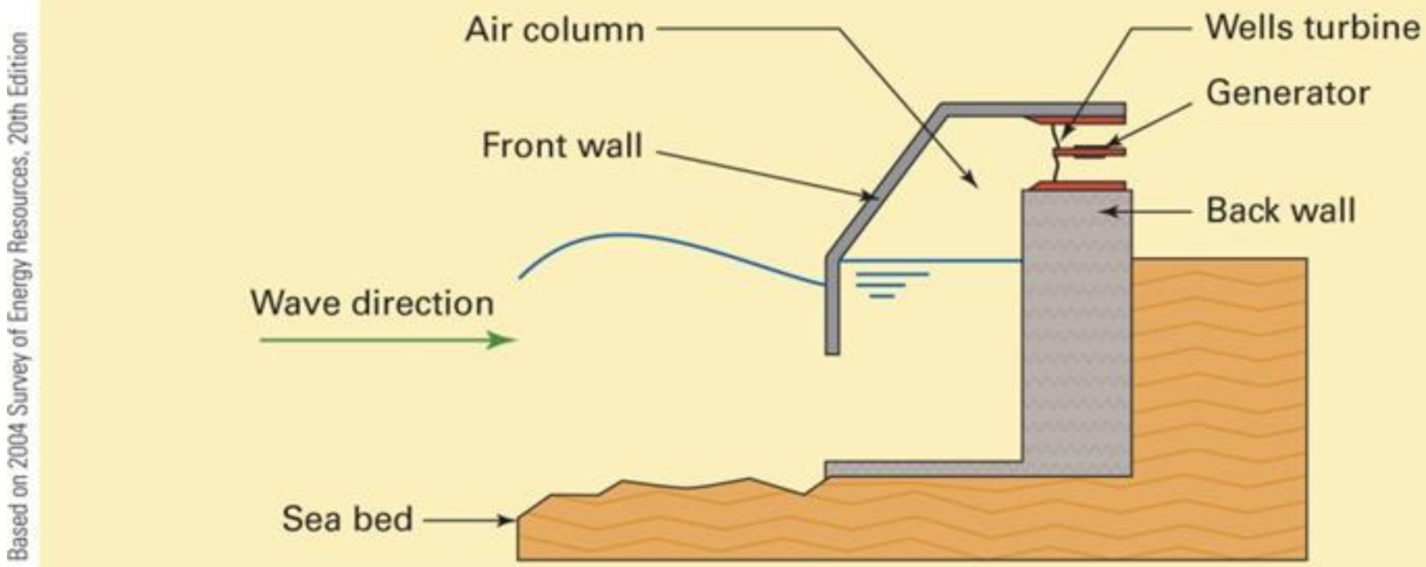


Figure 12.5: Schematic of an OWC.

Design of OWC turbine/generator assembly

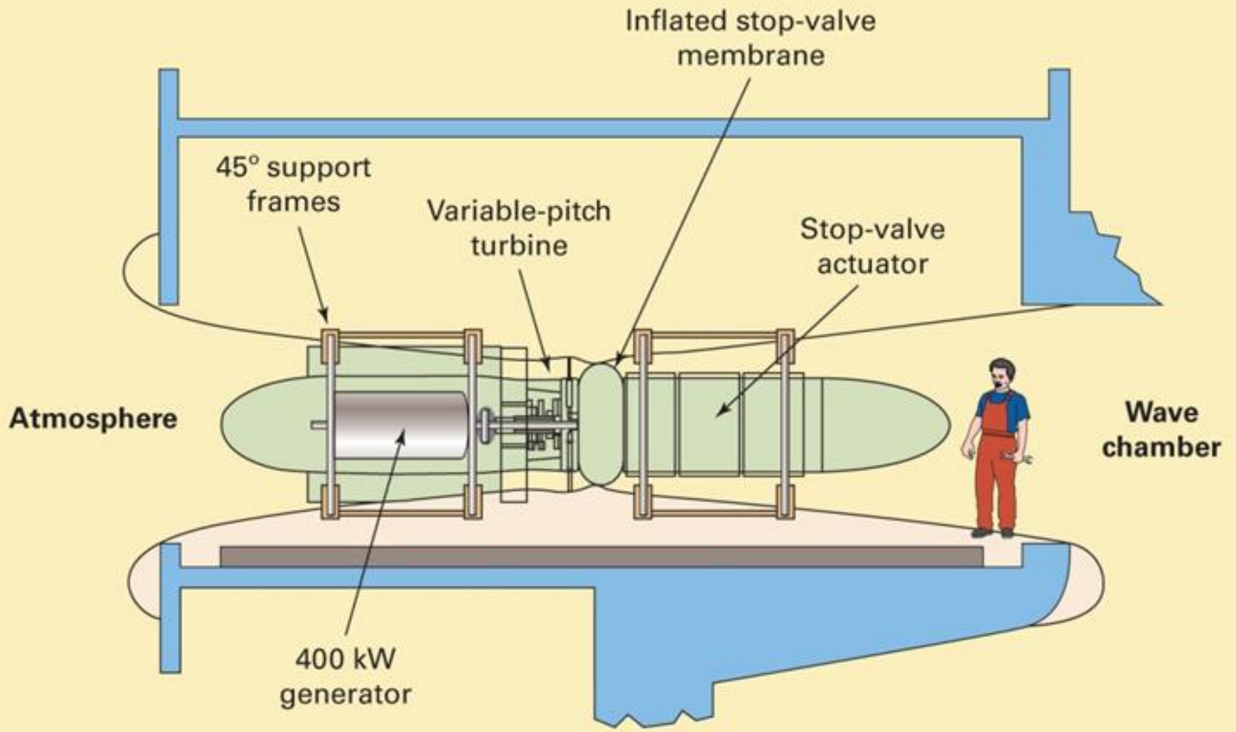


Figure 12.6: Details of the generator assembly of an OWC. The wave chamber is to the right in the figure.

Based on R.M. Taylor, N.J. Caldwell, "Design and Construction of the Variable-Pitch Air Turbine for the Azores Wave Energy Plant," Proc. Third European Wave Power Conference 30th September – 2nd October 1998, Patras

Bi-directional turbine

The turbine must turn in the same direction no matter which way the column of air is moving

One design uses a variable pitch turbine

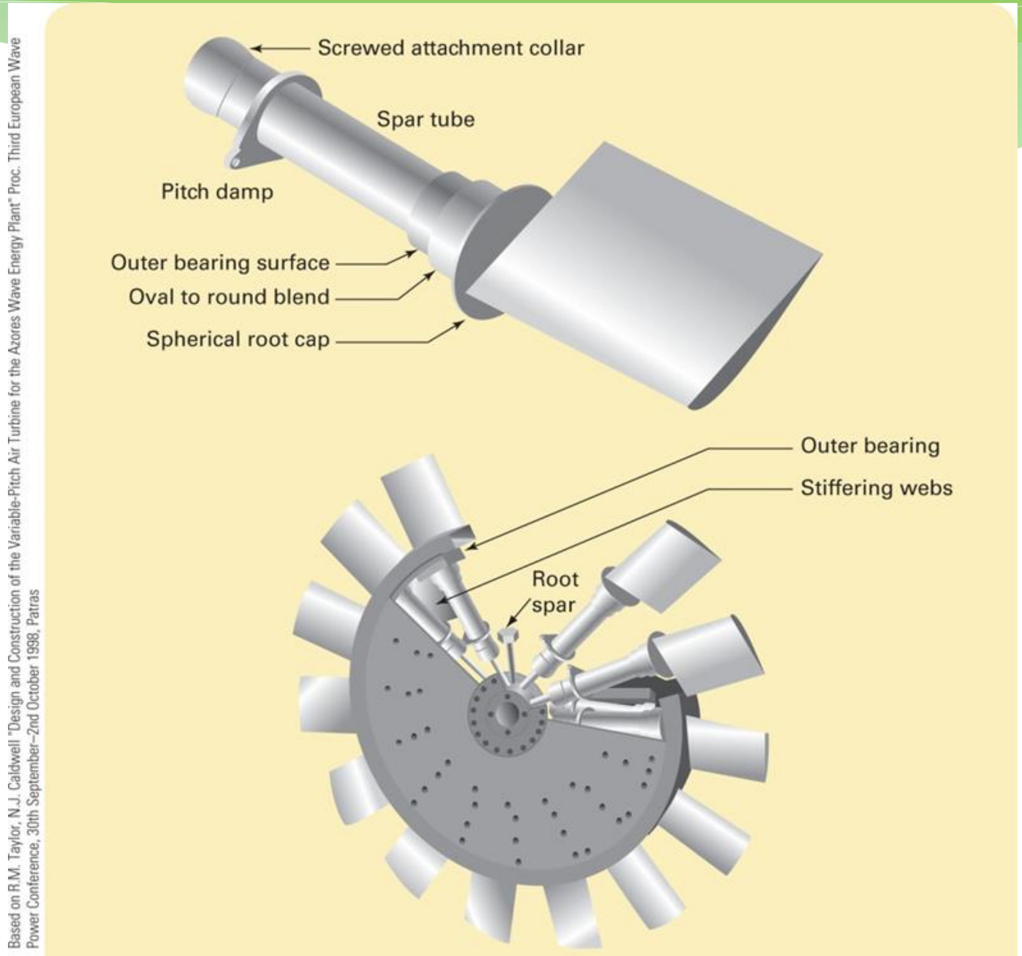


Figure 12.7: Design of a variable pitch turbine.

Wells turbine

A Wells turbine is a simpler design for a bi-directional turbine

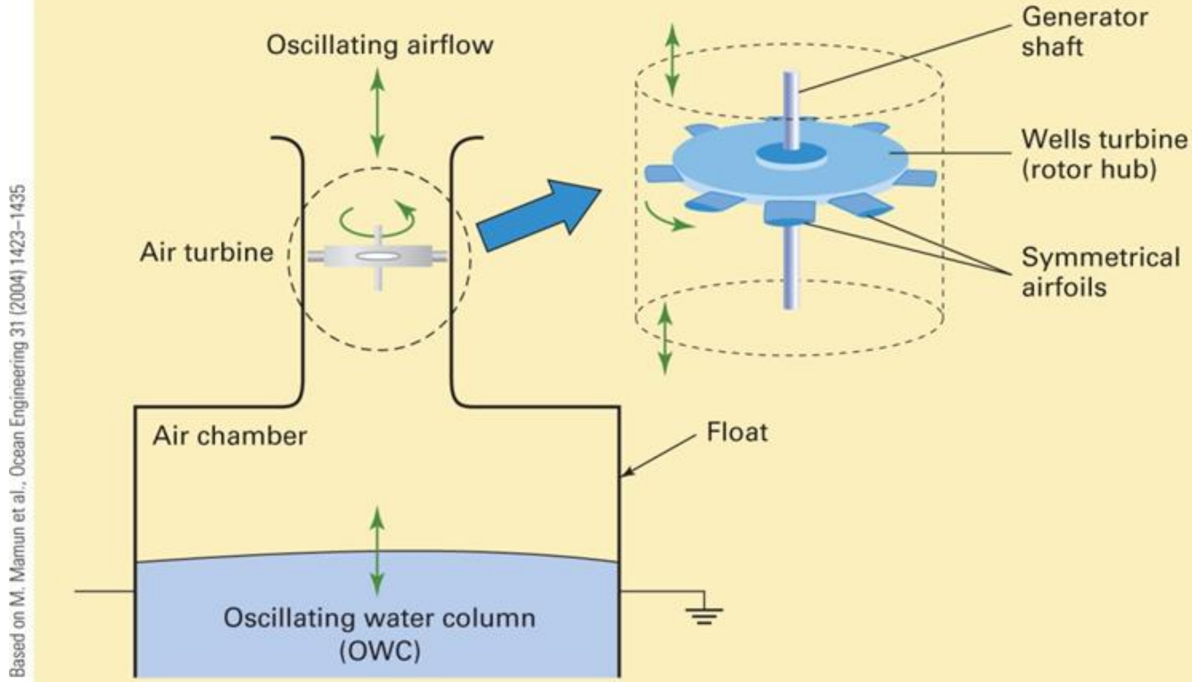


Figure 12.8: Design of a Wells turbine.

Floating and pitching devices

These are offshore devices that move up and down with the waves

The Pelamis has been one of the most successful

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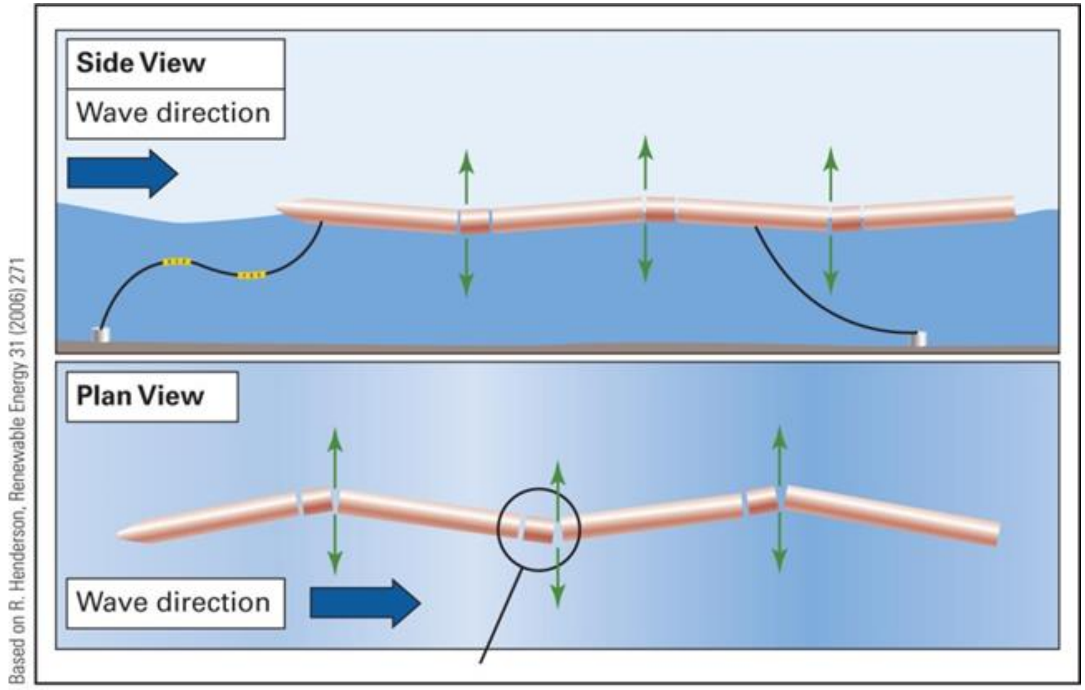
Figure 12.9: Pelamis prototype machine on-site at the European Marine Energy Centre off Orkney.

Design of a Pelamis

The Pelamis is made in several hinged sections

Flexing the hinges pumps hydraulic fluid through turbines to drive generators



Movement of a Pelamis in the vertical (top) and horizontal (bottom) directions.

Wave focusing devices

In a wave focusing device, waves travel up a ramp and then flow back into the ocean through turbine/generators

Devices are typically moored a few kilometers offshore

The Wave Dragon is an example of a wave focusing device

Schematic of a Wave Dragon

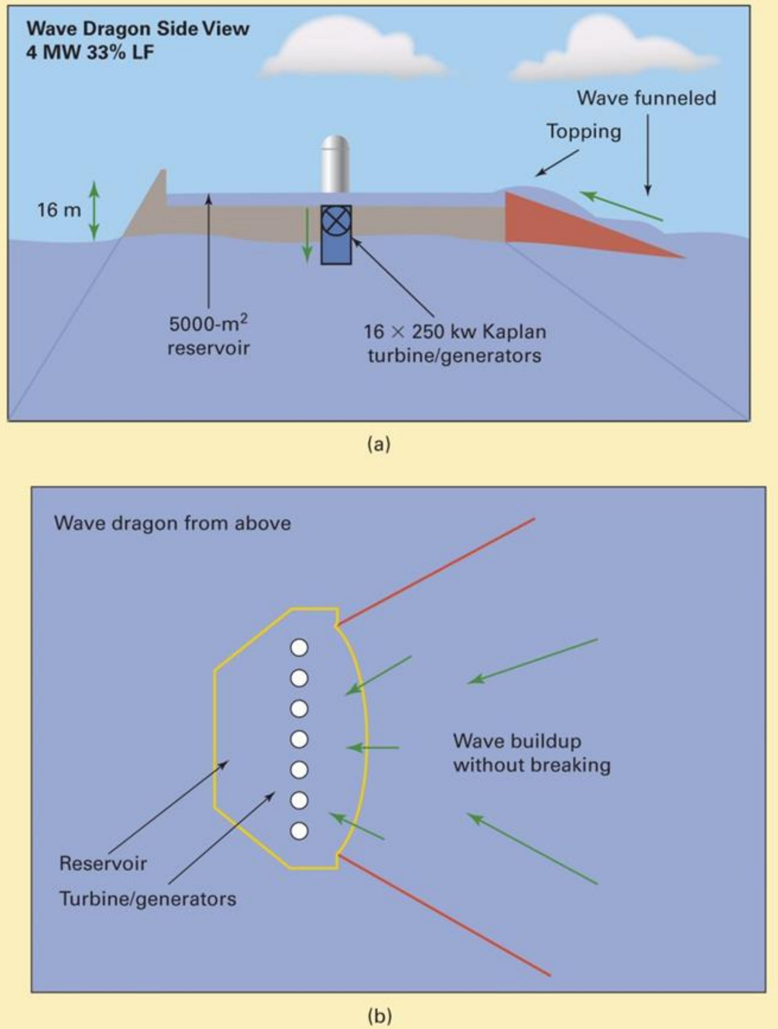


Diagram of Wave Dragon (prepared by Cengage) is "Based on http://www.climateandfuel.com/individualpageswavedragon.htm"

Figure 12.11: Schematic of the Wave Dragon: (a) side view and (b) top view.

Photograph of a Wave Dragon

Figure 12.12: Photograph of the Wave Dragon.

Summary

- Wave power can be as much as 100 kW per meter of wave front in some parts of the world
- Wave energy comes (equally) from the kinetic and potential energy associated with water
- Wave power devices can be characterized as
  - Oscillating water columns
  - Floating and pitching devices
  - Wave focusing devices
- An ambitious wave power development program might be able to produce a few percent of total world energy needs