WAVE ENERGY

B. Sørensen
Roskilde University, Denmark

Keywords : Resources, Environmental Considerations, Technology

Contents

Summary

Wave energy resources and technologies for extraction of power from waves are reviewed. Economic and environmental impacts are discussed.

1. Resources

Waves arise as a result of wind sweeping over an ocean surface exhibiting friction. In open oceans, the wave motion is dominated by gravity waves that are governed by the interplay between the gravitational force and the surface of the water. Their wavelength L and phase velocity U are related by the expression (Sørensen 1979):

$$U = (gL/2\pi + 2\pi s/Ld)^{1/2}$$

Where g is the gravitational acceleration at the surface of the ocean, s the surface tension of water against air, and d the density of water. The amplitude of the water surface of the oceans has a spectral distribution indicated in Figure 1, as function of the cycle time $T = L/U$. It is seen that the peak in the gravity wave spectrum is around $T = 8$ s. The amount of energy transferred from the wind system to the wave system globally is about 0.3 per cent (see Figure 1 in the tidal energy chapter). However, this does not mean that the options for extracting wave energy are exactly small. Wave energies of 50 kW m^{-1} found e.g. in the North Atlantic Ocean correspond to the integrated wind energy up to a height of around 200 m (Sørensen 1979). The total rate of energy transfer into waves (and subsequent dissipation), though, is about three times the current global electricity use and hence wave energy is strictly a limited source of energy.

The global distribution of annual means of wave energy is fairly uniform over the oceans, but as one approaches shores, there are substantial differences. An indication of selected averages is given in Figure 2. The decrease in power near shores is given by the fetch distance (in a model of waves being created by wind action over time), as illustrated in Figure 3. The seasonal variation for a mid-ocean location is given in Figure 4, showing time-duration curves similar to those found for wind at good locations.

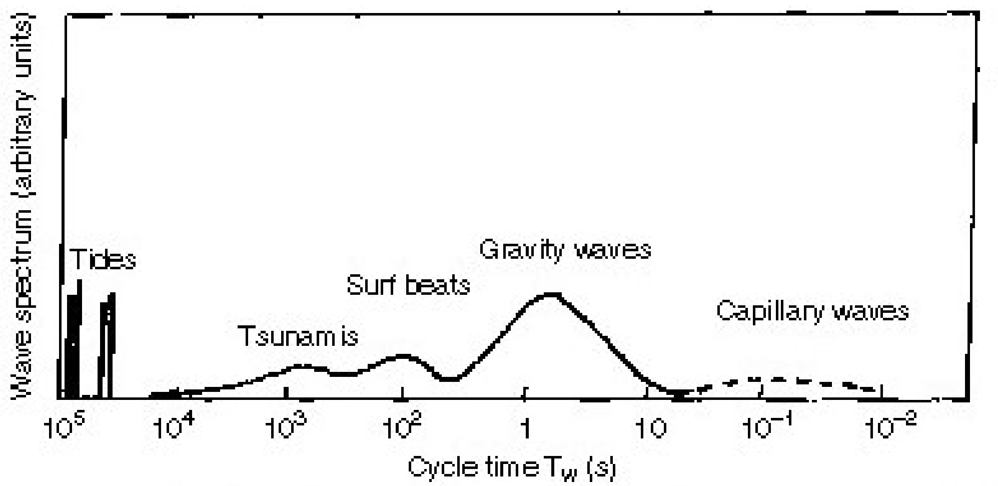

Figure 1. Indication of spectral decomposition of ocean wave amplitudes, averaged over time and position (Sørensen 1979).

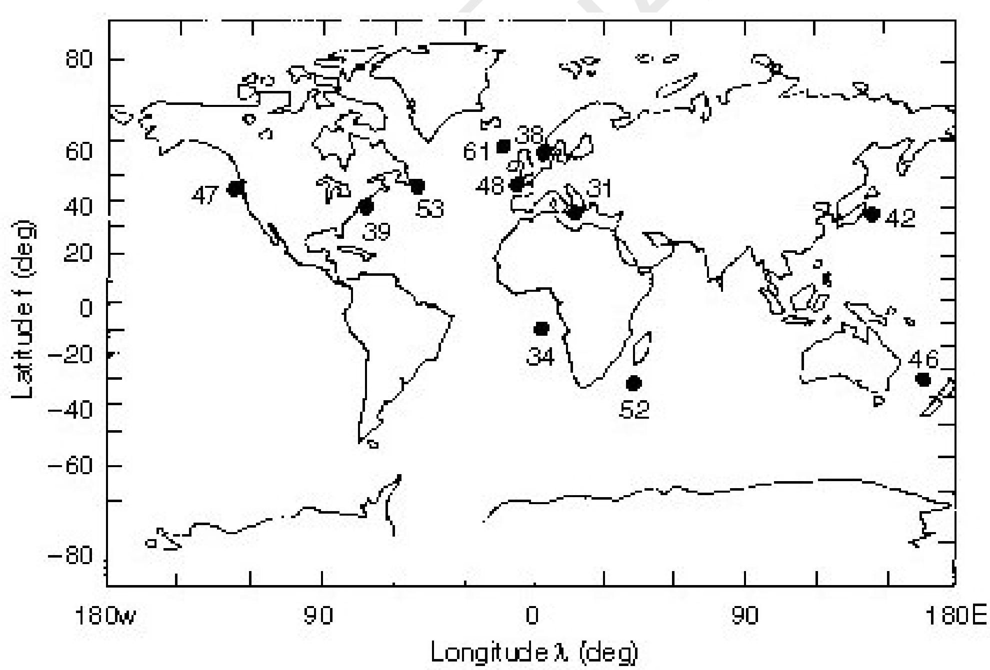

Figure 2. Annual average wave power (kW m^{-1}) for selected sites (ETSU 1976).

A more specific distribution of average wave power in a complex shore pattern such as that of Northern Europe is shown in Figure 5. Near the Irish coast, some high-power locations may be found, but even on the West Coast of Scotland, and certainly in the inner seas, the power level drops dramatically, corresponding in many cases only to wind energy integrated from the sea surface and a few tenths of meters upwards.

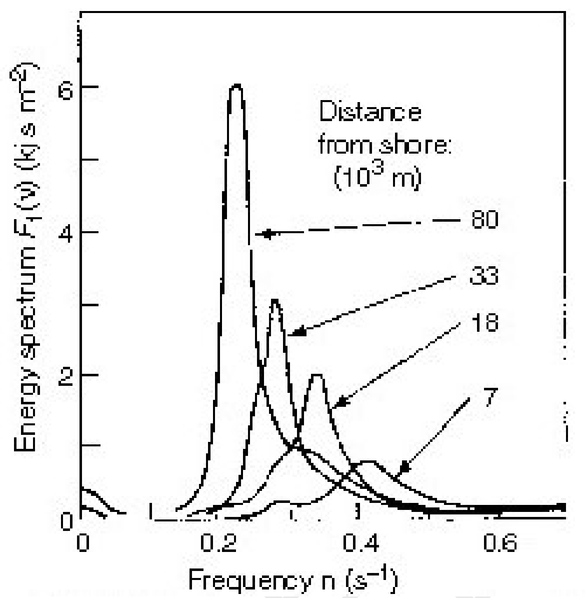

Figure 3. Fetch limited wave energy spectrum for the southern part of the North Sea (Hasselmann et al. 1973).

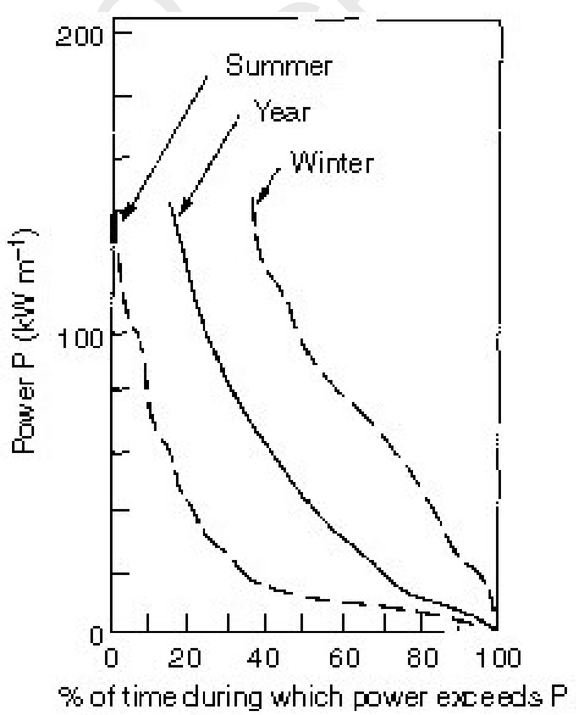

Figure 4. Time duration curves for power in the waves at Station India (Mollison et al. 1976).

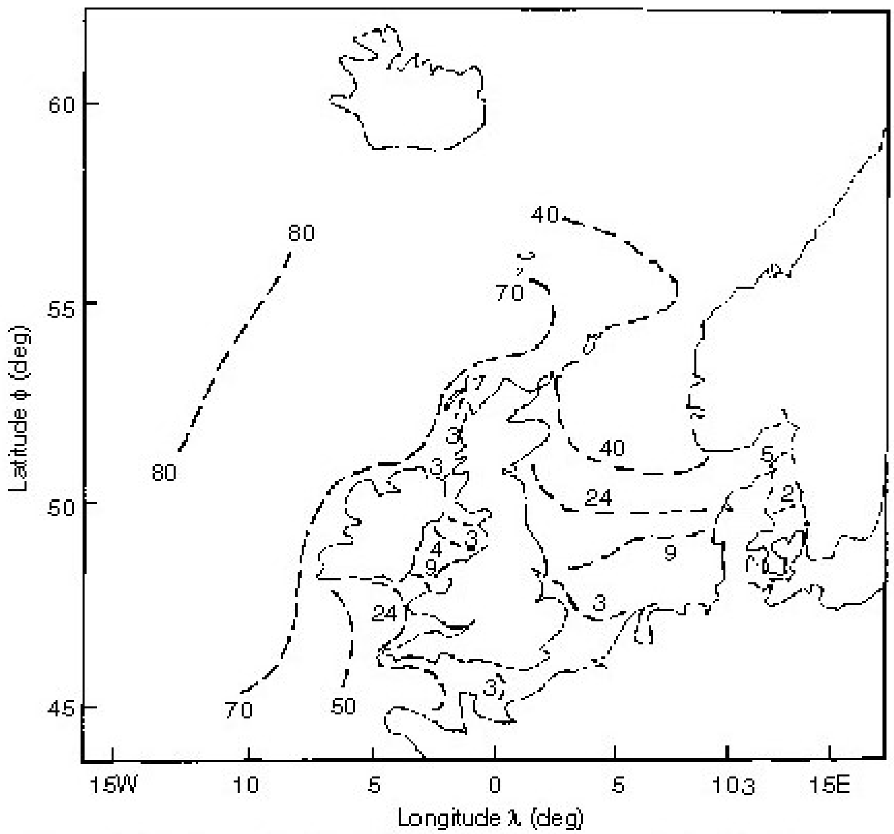

Figure 5. Contours of estimated average wave power in the North Sea and adjacent areas (kW m^{-1}) (ETSU 1976).

-
-
-

Bibliography and Suggestions for further study

A. Wokaun. Beyond Kyoto: The risks and how to cope. UN Framework Convention on Climate Change. Bonn, Germany, 16-25 June 2004

Al-Karaghouli A.A., Alnaser W.E. (2004), *Experimental comparative study of the performance of single and double basin solar-stills*. Appl Energy **77**(**3**), pp. 317-25.

Al-Karaghouli A.A., Alnaser W.E. (2004), *Performances of single and double basin solar-stills.* Solar Energy **78**(**3**), pp. 347-54.

Al-Shammiri M., Safar M(1999). Multi-effect distillation plants: state of the art. Desalination , 126:45-59.

Budal K and Falnes J (1982) Wave power conversion by point absorbers: A Norwegian project. *Int J Ambient Energy* 3, 59-67.

Cavanagh J, Clark F and Price R (1993) Ocean Energy Systems. *Renewable energy sources for fuels and electricity* (eds T Johansson, H Kelly, A Reddy and R Williams), pp. 513-547. Washington DC: Island Press.

Chafik, E., 2003. A new type of seawater desalination plants using solar energy. Desalination

Clarke F (1981) Wave Energy Technology. *Long-term energy sources* (R Meyer and J Olsen, eds), pp. 1296-1303. Boston: Pitman.

Corrado Sommariva ,(2010),COURSES IN DESALINATION, Thermal Desalination

Delyannis E. (2003), *Historic background of desalination and renewable energies.* Solar Energy **75**(**5**), Elsevier pp. 357-66.

ETSU (1976) *Wave Energy on UK coasts and North Sea*. UK Energy Technology Support Unit, Harwell.

Florides G., Kalogirou S. (2004), *Ground heat exchangers – a review.* Proceedings of third international conference on heat power cycles, Larnaca, Cyprus, on CD-ROM.

García-Rodríguez L. (2003), “Renewable energy applications in desalination: state of the art”, Solar Energy 75, 381-393.

García-Rodríguez, L., 2002, Seawater desalination driven by renewable energies: a review. Desalination 143: 103-113

Gregorzewski, A. and Genthner, K., High efficiency seawater distillation with heat recovery by absorption heat pumps. Proceedings of the IDA World Congress on Desalination and Water Reuse, pp. 97-113, Abu Dhabi, November 18-24, 1995.

Hasselmann K (1973) Deutschen Hydrographischen Zeitschrift, Suppl. Reihe A, No. 12.

Kalogirou S. (2003), *The potential of solar industrial process heat applications.* Appl Energy, **76**(**4**), pp. 337-61.Lysen E. (2003), *An outlook for the 21st century.* Renew Energy World, **6**(**1**), pp. 43-53.

Kalogirou S. (2004), *Solar energy collectors and applications.* Prog Energy Combust Sci, **30**(**3**), pp. 231-95

Karameldin, A. Lotfy and S. Mekhemar (2003), *The Red Sea area wind-driven mechanical vapor compression desalination system,* Desalination **153**, Elsevier pp. 47-53.

Kudish A.I., Evseev E.G., Walter G., Priebe T. (2003),*Simulation study on a solar desalination system utilizing an evaporator/condenser chamber*. Energy Convers Manage **44**(**10**), Elsevier, pp. 1653-70.

M.A. Darwish , Iain McGregor, (2005), *Five days' Intensive Course on - Thermal Desalination Processes Fundamentals and Practice,* MEDRC & Water Research Center Sultan Qaboos University, Oman

Masuda Y (1971) Paper presented at International Colloquium on Exploitation of the Oceans, Bordeaux.

McCormick M (1976). *Ocean Eng.* 3, 133-144

Millow B. and Zarza E., Advanced MED solar desalination plants. Configurations, costs, future – Seven years of experience at the Plataforma Solar de Almería (Spain), Desalination 108, pp. 51-58, 1996.

Mollison D, Bruneman and Salter S (1976) *Nature* 263, 223-226.

Müller-Holst, H., 2007. Solar Thermal Desalination using the Multiple Effec Humidification (MEH) method, Book Chapter, Solar Desalination for the 21st Century, 215–225.

Nielsen K (1991) Paper A7 presented at Third symposium on wave utilization, Tokyo: Japan Marine Science and Technology Center, Danish Wave Power Aps: Reports on Hanstholm Wave Energy Experiments (in Danish)

Parekh S., Farid M.M., Selman R.R., Al-Hallaj S. (2003), *Solar desalination with humidification-dehumidification technique – a comprehensive technical review.* Desalination **160**, Elsevier pp. 167-86.

Salter S (1974) *Nature* 249, 720-724.

Sayig A.A.M. (2004), *The reality of renewable energy*. Renewable Energy, pp. 10-15.

Sørensen B (1999) *Renewable Energy*. London: Academic Press.

Soteris A. Kalogirou (2005), *Seawater desalination using renewable energy sources*, Progress in Energy and Combustion Science **31**, Elsevier, pp. 242-281.

Thomson M., Infield D. (2003), *A photovoltaic-powered seawater reverse-osmosis system without batteries*. Desalination **153**(1-3), pp. 1-8

Tiwari G.N., Singh H.N., Tripathi R. (2003), *Present status of solar distillation.* Solar Energy 75(5), Elsevier, pp. 367-73.

Tzen E., Morris R. (2003), *Renewable energy sources for desalination.* Solar Energy **75**(**5**), Elsevier, pp. 375-9.

United Nations, Water for People, Water for Life – UN World Water Development Report, UNESCO Publishing, Paris, 2003.

Vindeløv S (1994) Research Activities in Wave Energy. *Sustainable Energy News*, No. 7, December, pp. 12-13.

Wiseman, R., Desalination business "stabilised on a high level" – IDA report, Desalination & Water Reuse 14(2), pp. 14-17, 2004.

World Energy Conference (1992) Ocean Energy. Chapter 3 in *Committee on Renewable Energy Sources: Opportunities and Constraints 1990-2020*. London.