POTENTIAL IMPACTS FROM OTEC-GENERATED UNDERWATER SOUNDS

James B. Rucker[1] and William A. Friedl[2]

[1]National Oceanic and Atmospheric Administration, Washington, DC
[2]Naval Ocean Systems Center, Hawaii Laboratory, HI

ABSTRACT

Oahu has been selected by the Ocean Thermal Corporation as the site for the first commercial ocean thermal energy conversion (OTEC) plant. The plant will be constructed offshore at Kahe Point in a water depth of 50 feet. The purpose of this paper is to report on research on the probable nature of the underwater sound generated by OTEC activities based on the plant design. Those findings will be applicable to assessing the plant's potential impact on marine biota, and possibly on the U.S. Navy Fleet Operational Readiness Accuracy Check Site (FORACS) range which is located nearby. Approximately 200 cubic meters of seawater must be pumped through the plant per second to generate the planned 40 megawatts of electricity. The seawater pumps will be the dominant source of underwater noise. A simple model of spherical acoustic spreading of the generated noise indicates that OTEC generated pump noise would have a spreading loss of 70 decibels at 3500 yards from the source, and would fall below the measured ambient noise of a sea state 1.

INTRODUCTION

Kahe Point on the Hawaiian Island of Oahu is a promising site for the construction of an ocean thermal energy conversion (OTEC) plant. For the past several years the site has been investigated by the Ocean Thermal Corporation (OTC) in an effort funded in part by the Department of Energy. OTC, under this jointly funded program, has developed a detailed preliminary design plan for an OTEC plant at Kahe Point. Although government funding of the effort has now been terminated, the Ocean Thermal Corporation is continuing its efforts to develop a 40 MWe OTEC plant at Kahe Point. This will be the first commercial scale OTEC plant ever constructed.

The purpose of this investigation has been to determine the probable nature of the underwater sound generated by the proposed OTEC plant. An OTEC plant of commercial size or comparable scale has never been built or operated so there is no precedent available to approximate the nature of the underwater sound. Instead, in this study, approximations were based on the machinery planned for the unit, the configuration of the seawater intake and discharge points and the proposed construction procedures. The results of this study will be applicable to the assessment of the potential acoustic impact on the local biota, especially marine mammals, and possibly on the U.S. Navy Fleet Operational Readiness Accuracy Check Site (FORACS) range which is located to the immediate north of the proposed OTEC site.

BACKGROUND

The process by which the virtually inexhaustible supply of energy that can be recovered in the vast warm-tropical regions of the world oceans is known as Ocean Thermal Energy Conversion (OTEC). OTEC uses the temperature differential between the warm surface water of the ocean and the cold water found at ocean depths to generate electrical power. The principle was first described in 1881 by a French physicist Arsene d'Arsonval. Fundamentally, warm surface seawater is pumped through a heat exchanger in which a low boiling working fluid, such as ammonia, is vaporized. The vapor then powers a turbine-generator, and passes into a condenser where it is cooled and liquified by cold seawater pumped from ocean depths. The liquified working fluid is then returned to the evaporator, vaporized again and the closed-loop cycle is repeated. This closed-loop cycle is the method that is proposed by the OTC (Figure 1).

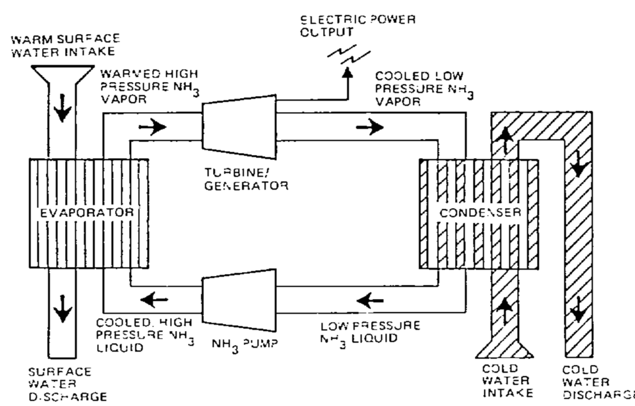

Figure 1. Closed-Cycle OTEC Schematic.

CONFIGURATION OF PROPOSED OTEC PLANT

The proposed 40 MWe OTEC power plant will operate as a closed-loop cycle using ammonia as the working fluid. The containment system that houses the power plant machinery and hardware will be a concrete, bottom-mounted structure approximately 240 x 370 feet, situated in 50 feet of water approximately 1800 feet offshore. The containment structure will be connected to the shoreline at Kane Point by a trestle 30 feet wide. The trestle will provide access to the OTEC plant and also will support the electrical transmission cables which will feed the generated electrical power into the Hawaiian Electric Company's (HECO) electrical grid system which is located near-shore.

Surface seawater to warm the evaporators will be drawn in a 20 x 120 foot opening in the shoreward face of the containment system. In addition, a 15 foot diameter pipe will be connected to the HECO discharge basin for supplemental energy. By using the thermal discharge of the existing HECO 600 MWe oil-fired plant, the OTEC plant will gain a thermal boost of several megawatts.

Cold seawater to cool the condensers will be drawn into the plant through a single 26 feet diameter cold water pipe (CWP) that will extend seaward from the containment structure across the narrow submerged shelf and down the island escarpment to a depth of approximately 2200 feet. The segment of the CWP that extends from the containment structure to edge of the escarpment at a 300 feet depth will be composed of reinforced concrete. The segment of the CWP that extends beyond the shelf escarpment edge will be composed of fiberglass reinforced plastic.

The warm and cold seawater, after passing through the evaporators and condensers respectively, will be mixed and returned to the ocean through two 25 foot diameter concrete effluent discharge pipes that will extend across the shelf to the escarpment located 300 feet below sea level (Figure 2).

The power system of the proposed OTEC 40 MWe plant will consist of four 10 MWe modules. Each module will consist of:

- 2 Cold Water Pumps
- 2 Condensers
- 2 Warm Water Pumps
- 2 Evaporators
- 1 Turbine-Generator Set
- 2 Ammonia Feed Pumps
- 2 Ammonia Reflux Pumps

The 8 cold water pumps will have approximately 1200 horse-power each and the 8 warm water pumps will be approximately 800 horse-power each. The pumps will operate at about 200 rpm.

SOURCES OF UNDERWATER NOISE

There are a variety of noise sources associated with both the construction and operation phases of the OTEC plant. During the construction phase a number of the construction techniques will generate both a broadband continuum of noise and a set of discrete frequency tonals or spikes in the broadband continuum. Construction activities such as blasting, excavation, pile driving and jet pumps, as well as barges and tugs that will be used to deploy the CWP, will generate a substantial amount of underwater noise over the planned two year construction period. However, the long term noise generated during plant operation over the 25-30 year life of the plant is of more ecological concern.

The principal probable sources of OTEC generated noise were studied by R. L. Allman (1984). It was found that the single most dominant source of noice would be that of the massive pumps that move nearly 200 m^3/sec seawater through the plant to obtain the energy needed to generate the 40 MWe of electrical power. Furthermore, these pumps are in direct communication with the ocean, whereas other machinery noise such as the small ammonia feed and reflux pumps and the turbine-generators are mechanically isolated by the heat exchangers and do not couple directly with the seawater.

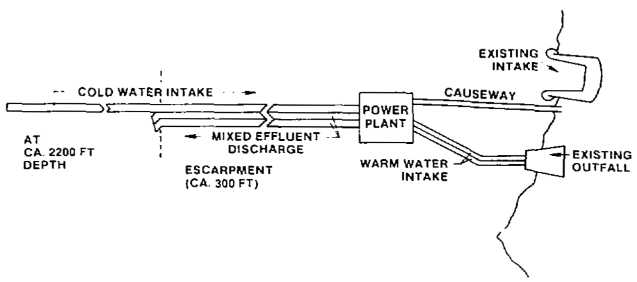

Figure 2. Plan-view of OTEC Plant Layout.

Other sources of OTEC noise include cold water pipe flow-induced wall vibration, effluent pipe-induced vibration and effluent jets. However these flow related resources were estimated to be far below the noise level estimated for the seawater pumps. A summary of the source levels estimated by R. L. Allman (1984) is given in Table 1.

TABLE 1 - ESTIMATED SOURCE LEVELS

I. Seawater Pump Noise

A. Broadband (All 16 pumps)
136 dB re 1 uPA@ 1 yd at 10 Hz
Decays as $f^{-1/2}$ from 10 Hz to 1 kHz

B. Discrete frequency tonals

Cold water pumps (All 8 pumps)
fundamental = 161 dB re 1 uPa 12.6 Hz
2nd harmonic = 138 dB re 1 uPa at 25.1 Hz

Warm water pumps (All 8 pumps)
fundamental: 164.5 dB re 1 uPa at 12.6 Hz
2nd harmonic = 141.5 dB re 1 uPa at 17 Hz

II. Cold Water Pipe

(Flow-induced wall vibration)

$I_0 = 7.1 \times 10^{-11}$ watt/m^2 at pipe wall
Peak at .49 Hz; decays as $f^{-1.65}$

III. Mixed Effluent Pipes

(Flow-induced wall vibration)

$I_0 = 9.2 \times 10^{-12}$ watt/m^2 at pipe wall
Peak at .28 Hz; decays as $f^{-1.65}$

IV. Effluent Jets

$I_0 = 1.3 \times 10^{-13}$ watt/m^2, on axis
Peak at .23 Hz; decays as f^{-2}

ACOUSTIC MODELING OF SEAWATER PUMP NOISE

The OTEC concrete containment structure that houses the 16 seawater pumps is designed to withstand storms, tidal waves, and seismic events. Its walls would be 2 feet thick and partially buried in the sediment. The large diameter cold seawater intake and effluent pipes from this structure also would be largely buried and formed of very heavy concrete out to the edge of the shelf escarpment at the -300 foot contour. Allman (1984) has suggested the adoption of a source model in which noise generated by the pumps is perfectly ducted down the conduits and released at the -300 foot effluent outlets, and also through the wall of the cold water pipe which changes to relatively thin plastic at the -300 foot depth contour. Acoustic transparency of the plastic pipe portion of the cold water pipe was assumed. In this way the acoustic source levels for the pumps can be modeled as if they originated from a point source at the -300 foot depth where the effluent pipes discharge. This estimate will probably err on the conservative side due to the assumption of a lossless duct.

The modeling effort at this time is limited to the noise generated by the seawater pumps and for the moment we are not focusing on the much weaker sound generated by flow-induced vibration in the seawater pipe, and at the effluent jets. Equal velocity in all directions, a zero bottom loss, and spherical spreading in deep water beyond the -300 foot escarpment has been assumed. The intensity of the sound spreading spherically is reduced at a rate of 6 dB for each doubling of the distance from the point of origin.

To determine the spreading losses in shallower water depth one should employ a cylindrical spreading model for acoustic ranges beyond two times the water depth. The intensity of sound spreading cylindrically is 3 dB for each doubling of the acoustic range.

Under these assumptions, OTEC sound of 136 dB at 10 Hz originating at the -300 foot point of effluent discharge would be reduced to 76 dB at 1000 yards, 70 dB at 2000 yards, 66.5 dB at 3000 yards and 64 dB at 4000 yards (Figure 3).

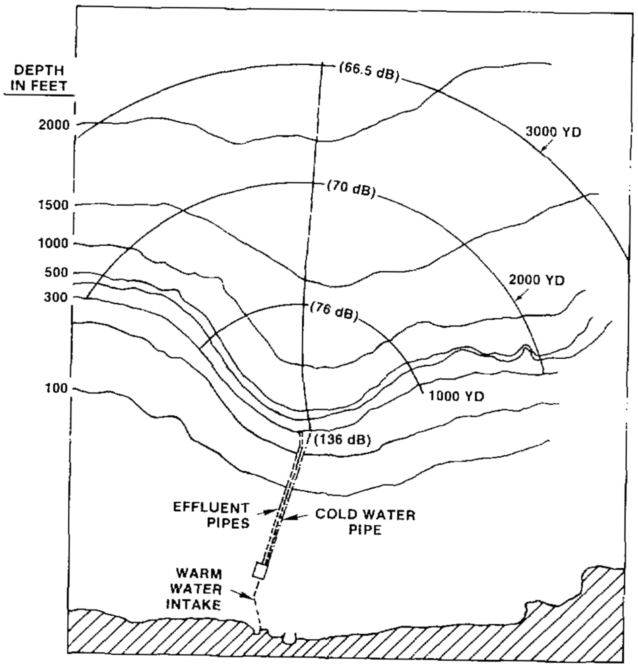

Figure 3. Theoretical OTEC Noise Loss with Range.

PROBABLE IMPACTS OF OTEC NOISE

Assuming the constraints of the model, one can calculate a conservative estimate of the acoustic spreading loss at the nearest sonar target in the Navy FORACS range which is about 2700 yards from the assumed OTEC point source. At the nearest FORACS sonar target, OTEC noise at 10 Hz would be reduced from the initial 136 dB to about 78 dB, and since the spectrum falls off at about $f^{-1/2}$ at higher frequencies, at 1 kHz the level of OTEC noise would be reduced by a spreading loss of about 71 dB to a level below 60 dB. It appears that OTEC generated sound reaching the Navy FORACS range will be sufficiently diminished to be less than the range maximum allowable levels for the frequencies involved. Actually the level of OTEC generated sound in the FORACS range will be less than that caused by a sea state of 1 which is a very gentle sea with waves less than 1 foot in height (Figure 4).

There will possibly be some effect on marine mammals and fishes near the plant. These marine organisms have been observed by other investigators to be affected by sounds in the frequency range (.5 Hz to 1.0 kHz) that will be produced by the OTEC noise (Turl, 1982). Additionally, it appears that waters out to about 2000 yards from the effluent discharge point source may be insonified with a noise level at 10 Hz that would be above the documented auditory thresholds for a number of species that are similar to those found in the water near Kahe Point (Gales, R.S., 1982; Popper and Fay, 1973). It is premature to speculate on just what the effects the OTEC generated noise will be on species indigenous to the Kahe Point environs. This is an area of research the authors are only now beginning to investigate.

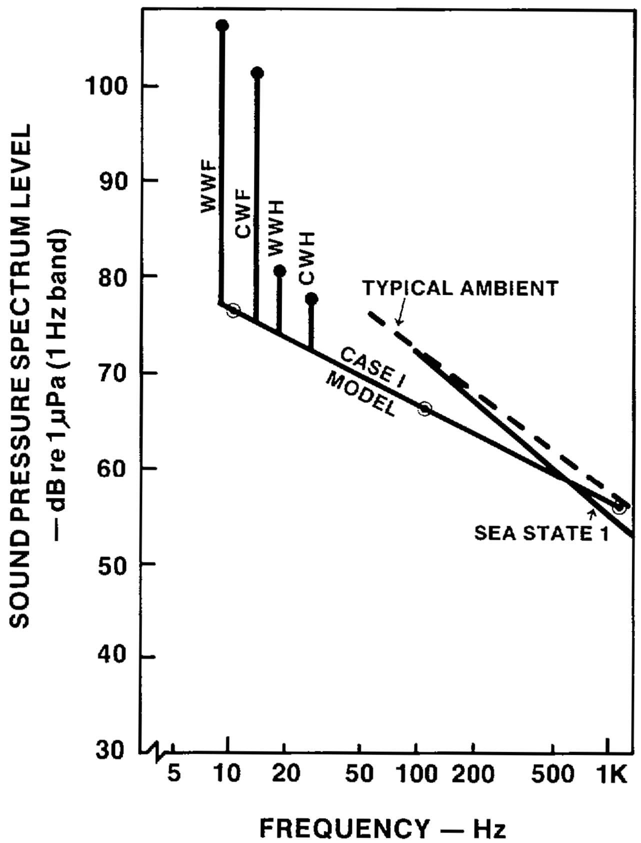

Figure 4. Estimated OTEC Noise and Ambient Noise Spectra. Case 1 model is OTEC pump noise at 2700 yards. WWF is the warm water pump fundamental and WWH is its fundamental harmonic. CWF is the cold water pump fundamental and CWH is its fundamental harmonic.

REFERENCES

Allman, R.L., 1984, OTEC Noise Impact Study (Preliminary Draft, NOSC Memo Ser 654/141-84).

Gale, R.S., 1982, Effects of Noise of Offshore Oil and Gas Operations on Marine Mammals - An Introductory Assessment, NOSC TR 884, VI & II.

Ocean Thermal Corporation, 1984, Preliminary Design Engineering Report. p. 191.

Popper, M.A. and R.R. Fay, 1973, Sound Detection and Processing by Teleost Fishes: A Critical Review, Jour. Acoust. Soc. Am., v. 53 p. 1515-1529.

Turl, C.W., 1982. Possible Effects of Noise from Offshore Oil and Gas Drilling Activities on Marine Mammals - A Survey of the Literature, NOSC TR 776.