Tropical Island Applications for Ocean Thermal Energy Conversion (OTEC)

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ABSTRACT

Ocean thermal energy conversion (OTEC) could be an important source of renewable base-load energy for tropical islands and would assist in relieving their present dependence on imported fossil fuels, particularly oil.

The importance of land-based OTEC installations is stressed for islands having a steeply shelving coast and which may, therefore, be able to exploit the ocean thermal resource close to shore. Plants of this type are currently in the design stage and these, together with a 100 kW pilot plant which recently completed successful trials on the Pacific island of Nauru, are described in this paper.

The ability to utilise land-based plants for co-production, i.e.,the generation of electricity plus freshwater production or mariculture, is emphasised and a computer cost-modelling simulation which was undertaken to determine the potential financial return from such a type of operation is described.

KEYWORDS

Ocean thermal energy conversion; renewable energy; tropical islands.

INTRODUCTION

Although many island nations in the tropics rely entirely on oil-fired steam or diesel generating facilities to meet their commercial energy requirements, the present high cost of importing oil has had an adverse effect on their economic stability. It is not surprising, therefore, that renewable energy technologies are now being seriously considered as eventual alternative sources of power for these islands.

One renewable energy source currently the focus of increasing attention is the thermal resource of the oceans. Between approximately 20 degrees north and 20 degrees south of the equator the ocean surfaces act as a vast solar collector and storage resevoir for the sun's heat, while below the surface at depths of approximately 1000m, polar currents maintain a low temperature a few degrees above freezing point. A constant temperature difference therefore exists between the surface and deeper ocean layers, which would provide the heat source and sink to operate a thermodynamic cycle and thereby generate electrical power.

Exploitation of this resource is known as ocean thermal energy conversion (usually abbreviated to OTEC). It is now regarded as a solar technology that offers non-depletable, non-polluting energy supplies. Although the low operating temperature difference (approximately 20°C) results in a low Carnot efficiency of about 2.5 per cent when all the various system losses have been taken into account, it must be remembered that the fuel costs will be zero. The constant availability of the thermal resource would enable OTEC to supply base-load power to an electricity grid.

OTEC CLOSED-CYCLE CONCEPT

Various proposals have been suggested for harnessing the thermal resource of the ocean by an OTEC plant, although the closed-cycle system based on the Rankine power cycle is currently the most popular. In this concept warm ocean surface water is pumped through an evaporator heat exchanger in which a secondary working fluid with a low boiling point, such as ammonia, is vaporised and power is generated by expansion of the vapour through a turbine connected to a generator. Upon leaving the turbine, the low pressure vapour is condensed in a second heat exchanger using cold seawater drawn up from the ocean depths as the cold-side fluid and is then pumped back to evaporator pressure ready for the cycle to re-commence. The concept is illustrated in Fig. 1.

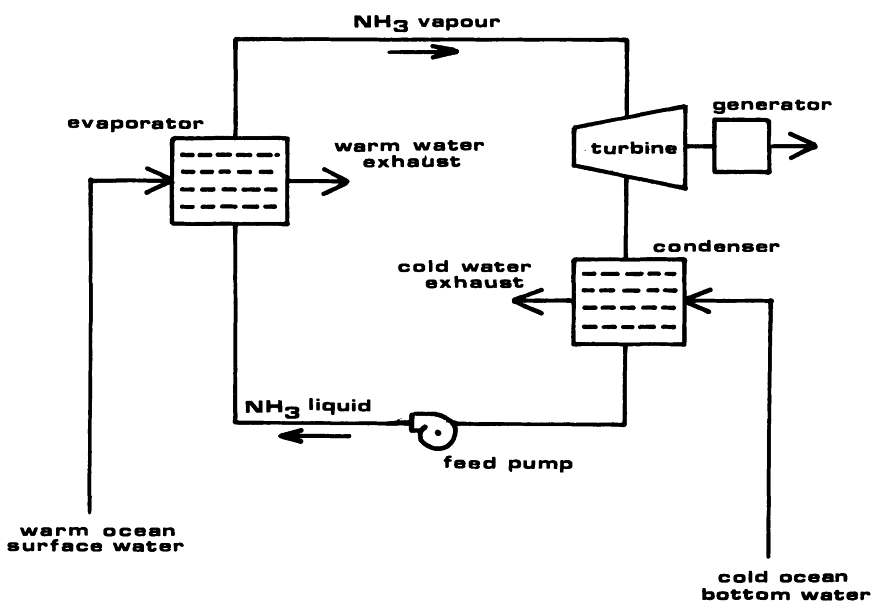

Fig. 1. OTEC closed-cycle concept.

DEVELOPMENT OF ISLAND OTEC INSTALLATIONS

While OTEC is not yet potentially competitive to coal-fired or nuclear plants, the rapid rise in the price of oil during the 1970's would, however, allow OTEC to compete favourably with oil-fired plants which are used by numerous tropical island countries.

Many tropical oceanic islands also rise steeply from the ocean floor with a deep cold water source thus lying close to shore. This topographical condition would favour the use of a land-based OTEC installation, thereby avoiding many of the technical difficulties and hazards associated with offshore work.

Japan has made a very significant contribution to the development of OTEC technology recently with the construction and operation of a 100kW land-based pilot plant on the island of Nauru in the equatorial Pacific Ocean. The plant was built during 1981 and was partly financed by a consortium of Japanese companies comprising the Tokyo Electric Power Service Company (TEPSCO), Shimizu Construction Company Limited and the Toshiba Corporation. Test operations commenced in October 1981 and continued for a period of one year. Freon was used as a secondary working fluid in a closed-cycle process with titanium shell-and-tube heat exchangers. (Titanium is considered the ideal material for OTEC heat exchangers due to its high strength, excellent corrosion and erosion resistance in seawater and compatibility with working fluids, particularly ammonia.)

Construction and deployment of the cold seawater intake pipeline involved the onshore assembly of 10m lengths of 700mm internal diameter polyethylene pipe to form a series of 50m long sections. The first section, positioned on a temporary landing stage, was pulled out to sea by a tug while further sections were jointed on at the landward end. Buoys attached to the pipeline kept it afloat until the entire 950m had been jointed together and towed into position whereupon they were released to allow the pipeline to sink onto the steeply shelving offshore seabed. This deployment sequence is illustrated in Fig. 2. The pipeline enabled seawater at a temperature of 7^{o} - $8^{o}C$ to be pumped up from a depth of 560m. This was used as the cold-side fluid in the plant's condenser. Warm water at $30^{o}C$ was drawn directly from the ocean surface for use in the evaporator. Details of the principal components of this pilot plant are listed in Table 1.

Although the Nauru pilot plant has now been taken out of commission, the twelve month test programme provided a variety of useful data on which to base the design of larger commercial- sized OTEC plants. For example, tests were conducted to assess the effect of seawater temperature variations on the plant's performance, possible control of marine biofouling of the heat exchangers using a sponge-ball cleaning device manufactured by the Japanese firm Taproge, the quantity of Freon consumed during operation, the rate of component deterioration and the effects of wave pressures in the surf zone on the operating characteristics of the warm water pump.

The general success of this project has resulted in plans being drawn up for a 2.5 MW commercial plant for Nauru, costing approximately £16 million, with construction due to start in late 1983.

Three other land-based OTEC plants are presently in the design stages and are intended for installation on tropical islands. The first is a 1 MW commercial pilot plant for Jamaica which is being developed by a Scandinavian group

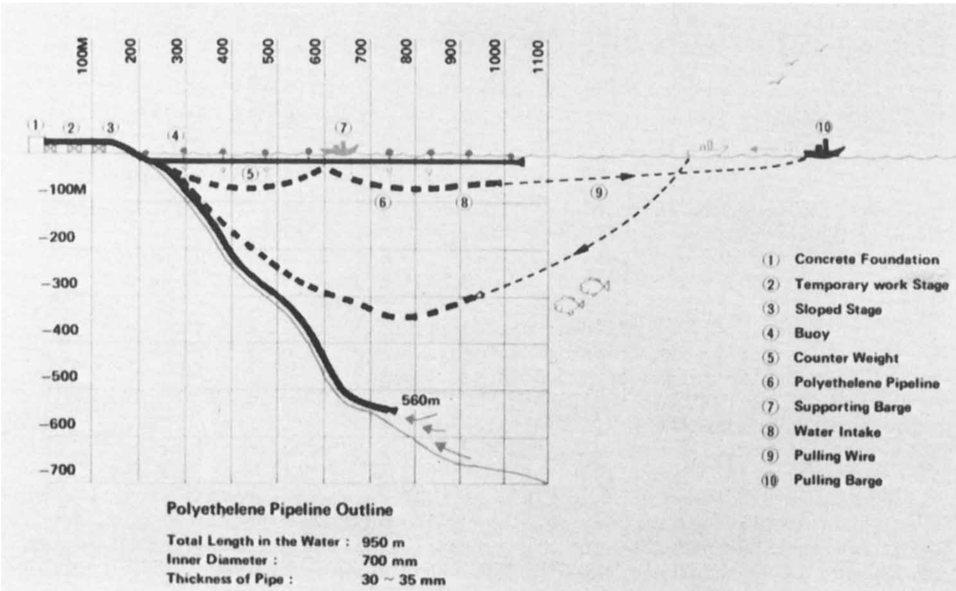

Fig. 2. Nauru 100 kW pilot plant cold water pipe deployment sequence. (Source: Tokyo Electric Power Service Company)

comprising Alfa Laval and SWECO of Sweden and Oy Wiik and Hoglund AB from Finland. Development of this plant follows an agreement signed in 1981 between the group and the Petroleum Corporation of Jamaica, a government corporation of the Ministry of Mining and Energy responsible for the development of alternative energy sources as well as oil prospecting and handling. The group has recently established test apparatus on Jamaica which includes four Alfa-Laval plate-type heat exchangers; two made from titanium and two from stainless steel, which are being used in a series of seawater biofouling tests.

The second island proposal is by a Dutch group consisting of Delta Marine Consultants and Hollandische Beton for a 0.5 MW land-based plant for the Indonesian island of Bali. Like the test facility on Nauru, the Bali plant will utilise a polyethylene cold water pipe extending to a depth of 650m on a sea-bed slope of 15 degrees. An interesting aspect of this project is that the OTEC plant will replace a 400 kW diesel generator presently supplying domestic electricity to the island.

The final scheme forms part of the French OTEC programme supervised by the Centre Nationale pour l'Exploitation des Oceans (CNEXO), which is the French Government ocean research and development agency. The Pacific island of Tahiti has been selected as the proposed site for a 5 MW land-based plant. Considerable research within the French programme is directed towards the development of OTEC open-cycle technology which uses the warm seawater itself as a working fluid. The seawater is flash-evaporated under vacuum to produce low pressure steam used to drive a turbine, after which it is condensed in a heat exchanger by cold seawater drawn up from the ocean depths. The resulting condensate will be fresh water in considerably large volumes and the potential benefit of such a by-product for an island like Tahiti, where fresh water supply often poses a major problem, is obvious. CNEXO has estimated that a 5 MW open-cycle plant could provide more than 8 million litres of fresh water per day. (Marchand, 1979)

TABLE 1 Nauru 100 kW Pilot Plant Equipment Specifications[1]

1. Freon Turbine	
type	axial flow compact type
rated output	100 kW
working medium	R-22 freon
main vapour pressure	10.5 atm.
main vapour temperature	24.7°C
turbine inlet flow	74 tonne/hr
rated speed	3000 rev/min
2. Generator	
type	open air-cooled, horizontal rotating field type
output	100 kW
voltage	415 V
frequency	50 Hz
3. Evaporator	
type	1 no. horizontal shell-and-tube type
warm water flow	1,450 tonne/hr (29.8°C)
4. Condenser	
type	1 no. vertical shell-and-tube type
cold water flow	1,410 tonne/hr (8.1°C)
5. Warm Seawater Pump	
type	1 no. horizontal centrifugal type
pumping capacity	23.7 m^3/min
6. Cold Seawater Pump	
type	1 no. horizontal centrifugal type
pumping capacity	22.9 m^3/min
7. Freon Pump	
type	1 no. horizontal centrifugal type
pumping capacity	1.0 m^3/min
8. Cold Water Pipe	
material	polyethylene
diameter	750 mm (ext.), 700 mm (int.)
total length	950 m
intake depth	560 m

1 Source; Tokyo Electric Power Service Company (TEPSCO)

SIMULATION OF A LAND-BASED OTEC INSTALLATION

In view of the increasing interest being shown in the land-based OTEC concept, a study was carried out at Manchester University during 1982 to determine the economic feasibility of a simulated plant installation of this type on a tropical island situated in the area of the southern Indian Ocean.

In addition to the supply of electricity to the island's power grid, it was considered appropriate to provide a mariculture facility linked to the OTEC plant, since it was anticipated that without revenue earned externally by the export of a by-product the relatively small 2.5 MW capacity chosen for the simulated plant could not be economically justified.

The simulation exercise covered the entire life span of the project from conception, through design, construction and operation to eventual phase-out or updating with a larger capacity plant, assumed to be at a time approximately 30 years hence.

Advantage was taken of two separate cost-modelling computer programmes made available through the University of Manchester Regional Computing Centre. The first, known as CASPAR (Computer Aided Simulation for Project Appraisal and Review), developed by the Department of Civil Engineering at the University of Manchester Institute of Science and Technology (UMIST), was used to model the overall project from inception through to closedown. A particular aim of the study was to analyse the construction phase of the project in some detail and the second program, known as PCM 3, was used for this purpose. This program developed by a commercial software company, Project Software Limited, London, was used to produce a time schedule and costs for the construction phase based on optimum utilisation of construction resources such as plant, materials and labour. In the case of an island location these resources would inevitably be limited and need to be imported from the nearest mainland.

Simulation of the project was split into a number of sequential stages comprising survey, design, construction and operational activities, and a network precedence diagram was prepared to show the inter-relationship of these activities and any timing constraints that would be necessary in their execution.

At the survey stage a variety of data would need to be collected on which to base the plant's design. The ocean survey, for example, would involve the collection of wave data over a certain period to determine a safe weather 'window' for planning deployment operations of the cold water pipeline in order to minimise wave-induced loading during the critical 'tow-out' stage. Bathymetry, i.e., the underwater contour depths, would also be a key factor in determining the optimum location for the plant to ensure that a fairly constant steeply shelving seabed existed.

Ocean temperature distribution both temporally and spatially would be measured to ensure that an average'delta T' value (the temperature difference between the upper and lower ocean layers which supply the plant's warm and cold water sources respectively) of at least 18^{o}C would be available throughout the year. The measurements would also determine to what depth the cold water pipe would need to be laid to reach a cold water source of constant low temperature.

Land-Based Plant Layout

Figure 3 indicates a general layout plan for the plant. The main components, i.e., heat exchangers, pumps and turbine would be housed individually in suitable structures erected on reclaimed land adjacent to the shore. The mariculture pond dimensions for this simulation were based on a relationship to OTEC plant capacity proposed by Kamogawa and Nakamoto (1981). Although the full extent of this pond is not shown in Fig. 3, it would cover an area of 250,000 m^2 with an average depth of 2.5 m. The pond would receive cold water discharge from the plant containing a high concentration of nutrients upwelled from the ocean depths. The nutrients in the form of inorganic nitrogen (nitrates, nitrites and ammonia) would be converted to phytoplankton protein in the pond and used as food for filter feeding shellfish or shrimp.

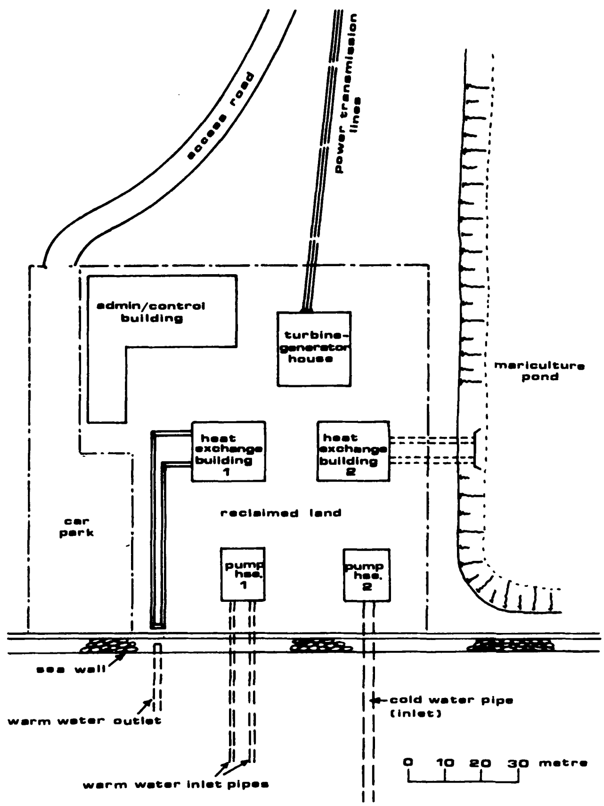

Fig. 3. Layout plan for land-based OTEC plant.

Construction Phase

The PCM 3 program used in the analysis of this phase provides a powerful means of modelling the future consequences of a construction programme in terms of money, resources and time. Execution of the program included a network analysis of the numerous diverse activities, ranging from onshore and offshore civil and structural items to manufacture and shipment of the various mechanical and electrical components. Available resource levels were modelled to determine what effect any resource limitation might have on the completion time for an activity. The program is able to carry out scheduling in such a manner that resource usage is optimised. In this way, high cost resources are applied to the various activities for as short a time as possible. Appropriate cost data was selected bearing in mind both the proposed geographic location of the plant and that the majority of mechanical and electrical components would probably have to be manufactured in Europe and shipped to the island.

Project Investment Appraisal

The investment appraisal using CASPAR attempted to assess the economic viability of the project by modelling the time, resource, cost and revenue dimensions. This analysis covered the complete process from conception to closedown. CASPAR produces a number of economic indicators based on cashflow analysis of the cost and revenue activities, including internal rate of return and net present value. Revenue was assumed to accrue from both the sale of electricity to island consumers and the export sales of shrimp cultivated in the mariculture pond.

Predicted cash flows used in an investment analysis of this type will be subject to error, as in any estimate. CASPAR contains sensitivity and risk analysis routines which permit evaluation of the effect of these errors on one or a number of financial parameters by producing forecasts of yields in probabilistic terms. The project was found to be most sensitive to variations in revenue from the sales of mariculture products; for example, a reduction of 25 per cent in the expected revenue level would reduce the internal rate of return by 10 per cent. Without these variations , an internal rate of return of 25.5 per cent and a net present value of £10.7 million was determined for the project.

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