Oceanographic characterization of areas of interest for a possible implementation of OTEC technology in Mexico

García-Huante Alejandro[1*], Ponce-Núñez, Francisco[2], Garduño-Ruíz Erika Paola[3], Bárcenas-Graniel Juan Francisco[4] and Luna-Gómez Víctor Enrique[5]

1. Estancias Posdoctorales por México, Consejo Nacional de Humanidades, Ciencias y Tecnologías (CONAHCYT). Colegio de Postgraduados campus Montecillo. Posgrado de Recursos Genéticos y Productividad, Orientación: Fisiología Vegetal. Carretera México-Texcoco Km. 36.5, Montecillo, Texcoco 56230, Estado de México. *Correspondence e-mail: alex_dodo@hotmail.com
2. Instituto de Ciencias del Mar y Limnología. Unidad de Procesos Oceánicos y Costeros. Circuito Exterior S/N, Ciudad Universitaria, Delegación Coyoacán, 04510, CDMX.
3. Posgrado en Ingeniería. Instituto de Ingeniería UNAM. Circuito Escolar, Ingeniería S/N, C.U., Coyoacán, 04510 Ciudad de México, CDMX.
4. Universidad del Caribe, Departamento de Ingeniería Ambiental. SM. 78, Mza. 1, Lote 1, esquina Fraccionamiento Tabachines. CP. 77528. Cancún, Quintana Roo, México.
5. Posgrado en Ingeniería. Instituto de Ingeniería UNAM. Circuito Escolar, Ingeniería S/N, C.U., Coyoacán, 04510 Ciudad de México, CDMX.

Keywords—**Mexican Pacific Ocean, Oceanographic characterization, OTEC**

I. INTRODUCTION

Mexico is a country that currently bases most of its energy production on fossil fuels. This type of resource is currently under pressure for various reasons, from the greater inaccessibility of declining crude oil reserves, to the lesser social acceptance of its use due to the high associated environmental and health impacts. This generates high volatility in costs and increases the country´s energy insecurity. For these reasons, it is particularly important to investigate and develop other energy generation options that satisfy current and projected national electricity demand, reducing social and environmental impacts. One of these options is known as OTEC (Ocean Thermal Energy Conversion) which takes advantage of the temperature difference between the surface and deep sea water to generate electricity. The areas that have exploitable thermal resources are the tropical and subtropical regions. Mexico has regions that are conducive to the implementation of this technology, the Mexican Pacific Ocean being an important area [1].

According to various investigations such as those done by [2], [3], [4], [5], [6], [7, 8], [9] and [10] there are several points of interest for the implementation of this technology in the country, based on different considerations: (a) the temperature difference between the surface and deep waters of the sea must be equal to or greater than 20° C, so that the thermal efficiency is adequate for obtaining electrical energy; (b) a maximum distance of 10-15 km between the coastline and the cold water pumping point, as well as a topographic slope between 15° and 20°; (c) adequate bathymetry of the coastal zone for construction; (d) low probability of extreme events; (e) a maximum depth for pumping cold water of 1000 m; (f) as well as good accessibility and low probability of ecological damage. In certain cases, in addition to electricity production, other by-products can be obtained that can trigger the social development of the area of interest, such as drinking water, air conditioning, aquaculture, mariculture, and cold-water agriculture, among others [1].

The central and southern areas of the Mexican Pacific Ocean have priority sites that meet the considerations described above, such as: (a) the Bahía de Banderas area in the polygon that includes the towns from Chimo to Playa Mismaloya, corresponding to the state of Jalisco; (b) the Petacalco zone in the state of Guerrero and (c) the Puerto Ángel area in Oaxaca, which includes the polygon from Punta Cometa to Bajo de Arenal (Fig. 1.). Various studies mention that the generation of net electrical power through OTEC in these areas can vary from 80–200 MW with an operational persistence of 70-100% [9, 1, 10]. For these reasons, it is extremely important to carry out research and field monitoring through oceanographic cruises that corroborate the theoretical results, such as temperature data in the oceanic vertical profile, fine bathymetry, and the type of sediments on the seabed of the sites preponderant. The results of these studies would give us sufficient certainty to know the feasibility of a possible installation and operation of an OTEC plant in Mexico in the medium term.

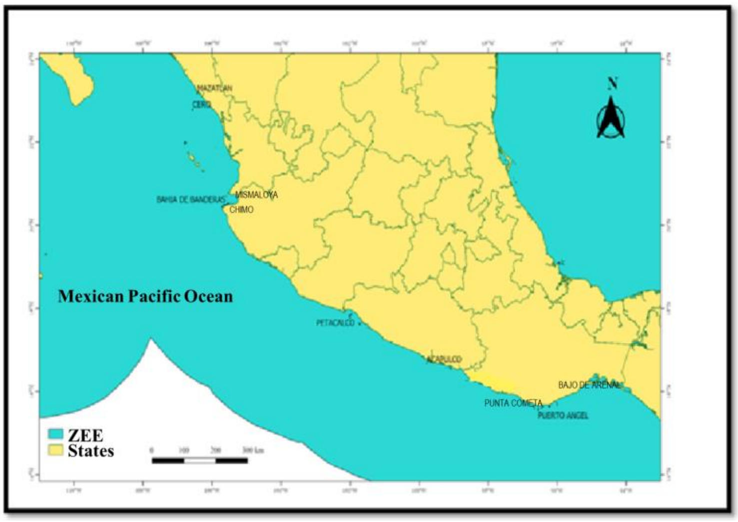

Fig. 1. Priority areas for OTEC in the Mexican Pacific Ocean

II. METHODS

A. *Bathymetric characterization*

During the OTEC-1 campaign in the R/V "El Puma" of the UNAM (Universidad Nacional Autónoma de México), bathymetric surveys were carried out in four areas of the Mexican Pacific, which were: A) Calibration; B) Banderas Bay; C) Petacalco Bay; and D) Puerto Angel. At the first site, a survey known as a "patch test" was carried out, which consists of the bathymetric record under specific conditions of speed and direction in several lines, in order to determine systematic errors in the EM300 equipment. Approximately 16.5 nautical miles were sailed and an area of 42,096 km² was covered. In this test, no systematic errors were found that affect the performance of the multibeam.

The first site of interest where a bathymetric survey was carried out was on the southern margin of Bahía de Banderas. In a first survey, navigation was carried out following lines parallel to the coastline with the aim of getting as close as possible to the recently acquired bathymetry. Available traffic data from the same OTEC-1 cruise ship were incorporated into this set, in order to gather as much information as possible. Approximately 100 nautical miles were navigated and 263,161 km² of bathymetric data were covered with a resolution between 5 m and 25 m. depths of up to 1850 m were observed.

In the case of the Petacalco area, navigation was carried out in a northwest direction, approximately following the coastline, with the objective of mapping the slope. This data set is complemented with those collected by Dr. Arturo Carranza in 2006, in front of the mouth of the Balsas River. Approximately 134 nautical miles were navigated and 450.87 km² of bathymetric data were covered with a resolution between 5 m and 25 m and depths of up to 1400 m were observed.

Finally, in the Puerto Ángel area, navigation was carried out in three directions, looking for lines parallel to the coastline, with the aim of mapping the slope and continental shelf. In the western sector, we navigated in a northwest-southeast direction; in the center in a direction approximately east-west; and in the east in a southwest-northeast direction. Approximately 235 nautical miles were navigated and 622.2 km² of bathymetric data were covered with a resolution between 5 m and 30 m and depths above to 2350 m were observed.

B. *Oceanographic conditions*

For the recording of CTD (Conductivity, Temperature and Depth) and oxygen measurements during the OTEC-1 campaign, as well as the taking of water samples at different levels, a SEABIRD11 brand SBE911 plus equipment was used. The CTD data processing was performed using the SBE Data Processing V. 7.26.7 (2018) program, developed by the manufacturer: SEABIRD Scientific. From a raw data hexadecimal file, through an ASCII format that contains various data: instrument, sensors, calibration, variables and their values, the different modules worked in cascade on this converted file. Only downcast data were used, being the best practice, because the measurements are made in undisturbed waters. The SBE11 on-board unit applied a temperature and conductivity alignment for 0.073 s, (approximately 2 scans). Oximeter sample alignment was applied for 2 scans (0.084 s). It was not necessary to apply the alignment for the fluorescence, turbidity and pH sensors, since the measurements are independent of the flow of water through the pipe. The conductivity measurement was made from the response time to the cell temperature [11] and through the "loop edit" processing, the data was filtered based on the rate of descent, to prevent data recorded when the equipment ascends and descends in the same body of water from being processed for computation of variables. This process is important when operating in conditions where the roll or drift of the ship causes the instrument to rise and fall as it ascends or descends. After calculating the derived variables, a cell average of these values was performed and averages per 1 m were calculated.

III. RESULTS

In Bahía de Banderas it is observed that the depths of interest for the implementation of the OTEC technology are between 3 and 4 km away from the coastline (Figs. 2 and 3). This would allow a decrease in pipeline and energy costs for pumping deep water, which is why it is a promising area, so detailed geomorphological studies must now be carried out to know the pertinent engineering implementations for the hydraulic part.

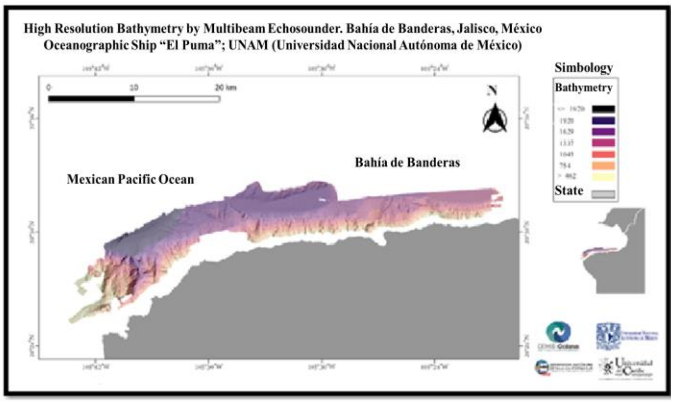

Fig. 2. Area of Bahía de Banderas, Jalisco.

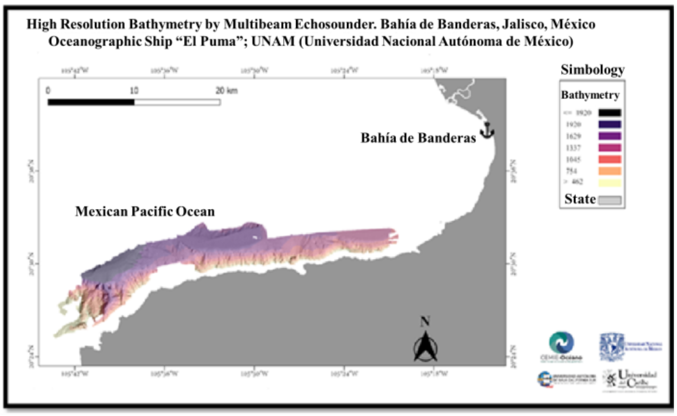

Fig. 3. General high-resolution bathymetry information for the Bahía de Banderas.

In the case of Puerto Ángel and the surrounding areas, the shortest distance between the coastline and the pumping area is located to the west of the bay (4 km) and the general average for the area is close to the isobath of 1000 m is 6.7 km (Figs. 4 and 5). Although this represents a higher cost in terms of the length of the pipes and their assembly in the area compared to Bahía de Banderas, this area is of high interest because the thermal gradient is maintained throughout the year, despite weather seasonality. This means that the thermal gradient can even be obtained Fig. 3 Area of Bahías de Huatulco, Oaxaca.below 1000 m depth in some areas, but the ideal way to maintain this temperature difference is to install the pipe to the highest depth.

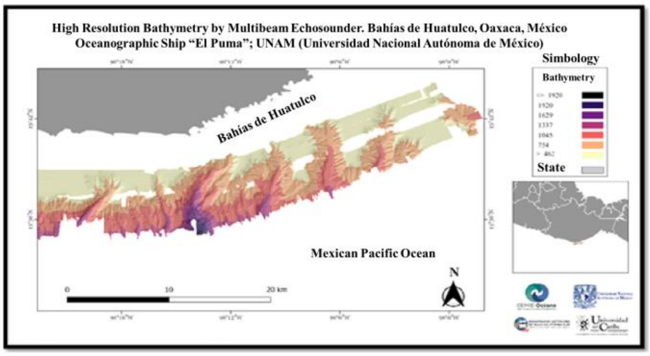

Fig. 4. Bathymetry of Bahías de Huatulco

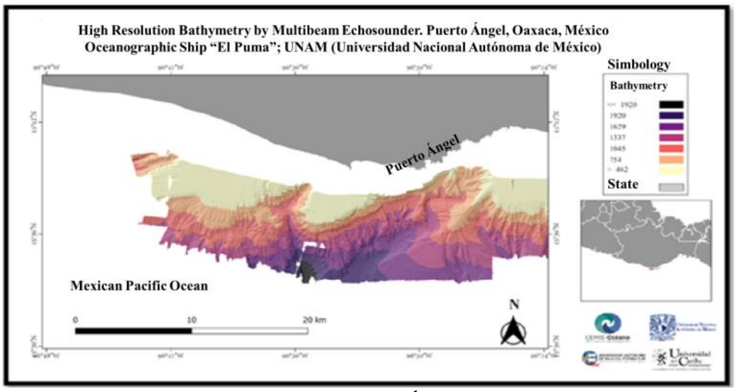

Fig. 5. Bathymetry of Puerto Ángel, Oaxaca

Finally, the area of Petacalco, Guerrero shows interesting areas where the distance to the coastline reaches 21 km for the installation of pipelines (Figs. 6 and 7). However, since there is a thermoelectric plant in the area, it has been thought that, in order to reduce costs for pipe installation, the hot water that comes out of the plant (approximately 60°C output) is used as hot water and the zone superficial (between 24 and 26°C) as if it were deep water to be used in the work cycle of the plant. In this way, in addition to the temperature difference being much greater, the expense for installing pipes drops considerably since it would no longer be necessary to reach high depths to have good thermal efficiency.

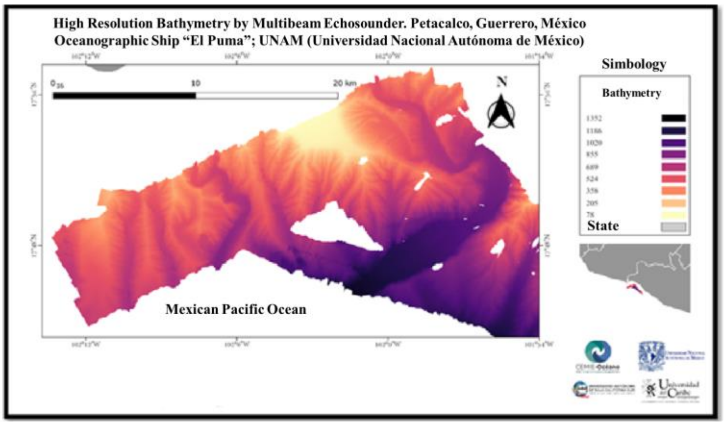

Fig. 6. Bathymetry of Petacalco

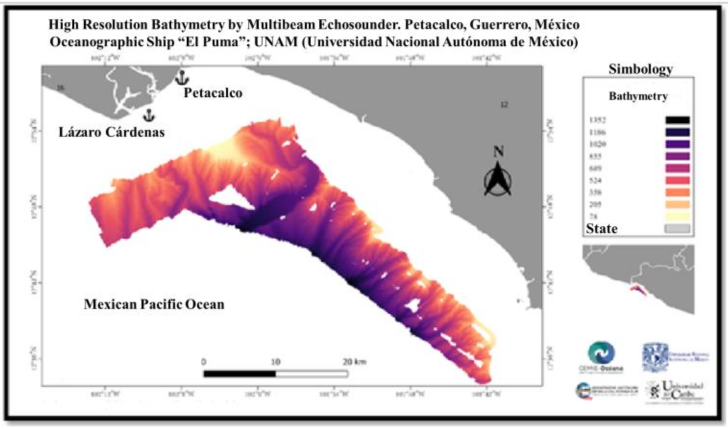

Fig. 7. Bathymetry of Petacalco and Lázaro Cárdenas

Regarding the results of the CTD, eight sets were made covering from the Marías Islands to Puerto Ángel. The depth of the measurements was different at each station, the shallowest being 930 m deep corresponding to station CTD09 in Bahía de Banderas and the deepest being 2050 m deep at station CTD07. Surface temperatures (at 5 meters depth) were in the range between 19.53°C and 26.89°C, in Bahía Banderas and Puerto Ángel respectively. The warmest stations were CTD05 (Puerto Ángel), CTD06 (Pinotepa Nacional) and station CTD08 (Petacalco). The salinity profiles were maintained between 34.3 UPS and 35 UPS, with the halocline at a depth of 100 m and where the highest salinities generally obtained in all stations except station CTD02 (Islas Marías) where the salinity on the surface was the largest of the entire measured water column (1500 m deep). It was observed that after the thermocline, the profiles do not show great dispersion. According to the ship course, two transects were obtained and allowed graphing the variation of temperature and salinity profiles between transects. These were:

- Transect A-B. Banderas Bay from station CTD03, CTD04 and CTD09.
- Transect B-C, Puerto Escondido-Lázaro Cárdenas, CTD05, CTD06, CTD07 and CTD08.

The first transect consisted of a little more than 11 km consisted of three CTD stations, being located at its closest point to the coast at 3 km where the depth already exceeds 1000 m deep and reaching vertical thermal gradients of between 15 and 20 °C. It was observed that stations CTD03 and CTD04 are the ones with the highest surface temperature (Towards the center of the bay), but at approximately 120 m depth the temperature profile of the three stations were more uniform.

The second transect consisted in 650 km transect and four CTD stations, being located at its closest point to the coast at 11 km (Puerto Ángel) where the depth is around 1800 m deep, reaching vertical thermal gradients of over 20°C at a depth of 1000 m in the case of Puerto Ángel (CTD05) and station CTD06. Regarding the concentration of dissolved oxygen, station CTD08 (Petacalco) has the highest concentration of dissolved oxygen, but from a depth of 160 meters the concentrations begin to standardize.

IV. DISCUSSION & CONCLUSION

During the OTEC-1 oceanographic cruise, bathymetry data were obtained to map the areas with the greatest potential for the installation of an OTEC-type ocean thermal energy plant. The depth within which the water reaches the adequate temperature to generate a thermal gradient equal to or greater than 20°C with respect to surface water was identified in each zone. It was evidenced that these areas have a distance from the coastline less than that considered theoretically. It was possible to observe and measure some important characteristics that must be considered within the planning for the installation of an OTEC-type plant, such as bathymetry, currents and the physiochemistry of the water masses. From the bathymetric analysis it was possible to determine the shortest distance from the coastline to the zone in which the deep water reaches a thermal gradient equal to or greater than 20°C. With the mapping carried out and visualized in 3D, it was possible to verify the type of bottom and the type of slope of each site. This information can be used for the installation and deployment of the OTEC plant structures (e. g. pipes). With the data obtained through the CTD coves, it can be identified that the thermal gradient between surface water and deep water exceeds 20°C from 700 m deep in Puerto Ángel and Petacalco; and from 900 m in Bahía de Banderas. On the other hand, the salinity profiles remained between 34.3 UPS - 35 UPS, with the halocline at a depth of 100 m. The dissolved oxygen data showed that the greatest variability is found on the surface and, from a depth of approximately 120 m, the concentrations begin to homogenize.

It can be affirmed that the proposed objectives have been met, obtaining compelling data that proves that within the three sites studied there are specific points with great potential for the installation of an OTEC plant. It is demonstrated that, according to their bathymetry, the areas with the least distance from the deep water intake to the coastline are: (1) Bahía de Banderas, (2) Puerto Ángel, and (3) Petacalco; and according to its temperature, the areas with the greatest thermal gradient are: (1) Puerto Ángel, (2) Petacalco and (3) Bahía de Banderas.

REFERENCES

[1] García Huante, A. Determinación del potencial energético del Océano Pacífico Mexicano: Gradiente Térmico. Tesis doctoral. Posgrado en Ingeniería Civil. Instituto de Ingeniería. Universidad Nacional Autónoma de México, Ciudad de México. 2021.
[2] Löhnberg A. (1960). Energía térmica del mar Banco Chinchorro, Quintana Roo. México. Ciudad de México, México. Recuperado de la Base de datos de la Biblioteca del Archivo Histórico del Agua (AHA).
[3] Vázquez de la Cerda, R. Primera Reunión sobre: El desarrollo y perspectivas de los mares mexicanos. Proyecto ATL–KIU-IPN. ESIA. Sociedad mexicana de Geografía y Estadística. Ciudad de México, octubre de 1990.
[4] Crews, R. 1997. OTEC Sites. Available: http://www.trellis.demon.co.uk/reports/otec_sites.html
[5] Aviña-Jiménez, H. Factibilidad de instalar una planta OTEC (Ocean Thermal Energy Conversion) en las costas de México. Tesis de Licenciatura. Universidad Nacional Autónoma de México, Ciudad de México. 2007.
[6] Bárcenas-Graniel, J. Evaluación del potencial energético renovable del Caribe Mexicano. Tesis de maestría. Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Ciudad de México. 2014.
[7] García-Huante, A. Posibles efectos oceanográficos por la operación de una planta OTEC en puerto Ángel, Oaxaca, México. Tesis de Maestría. Posgrado en Ciencias del Mar y Limnología. Universidad Nacional Autónoma de México, México. 2015.
[8] García Huante, A.; Rodríguez Cueto, Y.; Silva, R.; Mendoza, E.; Vega, L.A. 2018. Determination of the Potential Thermal Gradient for the Mexican Pacific Ocean. J. Mar. Sci. Eng. 6, 20. https://doi.org/10.3390/jmse6010020

[9] Hernández-Fontes JV, Felix A, Mendoza E, Cueto YR, Silva R. On the Marine Energy Resources of Mexico. Journal of Marine Science and Engineering. 2019; 7(6):191. https://doi.org/10.3390/jmse7060191
[10] Garduño-Ruiz, E. P.; Silva, R.; Rodríguez-Cueto, Y.; García-Huante, A.; Olmedo-González, J.; Martínez, M. L.; Wojtarowski, A.; Martell-Dubois, R.; Cerdeira-Estrada, S. 2021. Criteria for Optimal Site Selection for Ocean Thermal Energy Conversion (OTEC) Plants in Mexico. Energies, 14, 2121. https://doi.org/10.3390/en14082121
[11] Lueck, R. G. and Picklo, J. J. 1990. Thermal inertia of conductivity cells: observations with a Sea-Bird Cell, Journal of Atmospheric and Oceanic Technology, 7(5), 756-768. Retrieved May 18, 2022.