Study of Ocean Thermal Energy Conversion (OTEC) Generation as Project of Power Plant in West Sumatera-Indonesia

A. Fanny Octaviani, B. Muswar Muslim, C. Danny Faturachman, D. Ayom Buwono

Abstract**—** Ocean Thermal Energy Conversion (OTEC) is a field of science that is still less developed in the area of renewable energy sources for electricity utilization. Yet the potential of the OTEC is very large, especially in countries whose land is crossed by the equator. This study focuses on one part of the region of Indonesia which has the potential OTEC that is large enough in the area of West Sumatera. There are several points West Sumatera region that has the potential for the development of electric power installation on the utilization of seawater temperature difference waterwheel region of western Sumatera, especially the West Sumatera. From depth size coastline is very adequate for the OTEC plant was built.

Keywords**—** Indonesia, OTEC, power plant, renewable energy

I. Introduction

OTEC offers one of the most benign power production technologies, since the handling of hazardous substances is limited to the working fluid (ammonia), and no noxious by-products are generated. OTEC requires drawing seawater from the mixed layer and the deep ocean and returning it to the mixed layer, close to the thermo cline, which could be accomplished with minimal environmental impact. The carbon dioxide out-gassing from the seawater used for the operation of an OC-OTEC plant is less than 1% of the approximately 700 gram/kWh amount released by fuel oil plants. The value is even lower in the case of a CC-OTEC plant.

To have effective heat transfer it is necessary to protect the heat exchangers from bio fouling. It has been determined that bio fouling only occurs in OTEC heat exchangers exposed to surface seawater. Therefore, it is only necessary to protect the CC-OTEC evaporators. Chlorine (Cl_2) has been proposed along with several mechanical means. Depending upon the type of evaporator, both chemical and mechanical means could be used.

Other potentially significant concerns are related to the construction phase. These are similar to those associated with the construction of any power plant, shipbuilding and the construction of offshore platforms. What is unique to OTEC is the movement of seawater streams with flow rates comparable to those of rivers and the effect of passing such streams through the OTEC components before returning them to the ocean. Both ammonia and chlorine can damage the eyes, skin, and mucous membranes, and can inhibit respiration. Ammonia is used as a fertilizer and in ice skating rink refrigeration systems. Chlorine is used in municipal water treatment plants and in steam power plants. Chlorine can be generated in situ; therefore storage of large quantities of chlorine is not recommended.

OTEC plant construction and operation may affect commercial and recreational fishing. Fish will be attracted to the plant, potentially increasing fishing in the area. Enhanced productivity due to redistribution of nutrients may improve fishing. However, the losses of inshore fish eggs and larvae, as well as juvenile fish, due to impingement and entrainment and to the discharge of biocides may reduce fish populations. The net effect of OTEC operation on aquatic life will depend on the balance achieved between these two effects. Through adequate planning and coordination with the local community, recreational assets near an OTEC site may be enhanced.

Other risks associated with the OTEC power system are the safety issues associated with steam electric power generation plants: electrical hazards, rotating machinery, use of compressed gases, heavy material-handling equipment, and shop and maintenance hazards. Because the CC-OTEC power plant operates as a low-temperature, low pressure Rankine cycle, it poses less hazard to operating personnel and the local population than conventional fossil-fuel plants. It is essential that all potentially significant concerns be examined and assessed for each site and design to assure that OTEC is an environmentally benign and safe alternative to conventional power generation. The consensus among researchers is that the potentially detrimental effects of OTEC plants on the environment can be avoided or mitigated by proper design.

1. OTEC Basic Theory

There are two approaches to the extraction of thermal energy from the oceans, one referred to as “Open-Cycle”, “Closed-Cycle” and A Hybrid System, two-stage arrangement for the production of electricity and freshwater also appears to have some attraction.

A. OTEC for Open Cycle

Open-cycle OTEC uses the tropical oceans warm surface water to make electricity. When warm seawater is placed in a low-pressure container, it boils. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam,

F. A. Fanny Octaviani is with the Darma Persada University, Jakarta, Indonesia (corresponding author to provide phone: +62218649053; fax: +62218649052; e-mail: fanny_octaviani@yahoo.com).

S. B. Muswar Muslim, was with the University of Indonesia, Indonesia (e-mail: muswar_2000@yahoo.com).

T. C. Danny Faturachman is Darma Persada University, Jakarta, Indonesia (e-mail: fdanny30@yahoo.com).

D. Ayom Buwono is Darma Persada University, Jakarta, Indonesia (email:abuwono.energi@gmail.com).

which has left its salt and contaminants behind in the low-pressure container, is pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water. This method has the advantage of producing desalinized fresh water, suitable for drinking water or irrigation as shown in Figure 2.

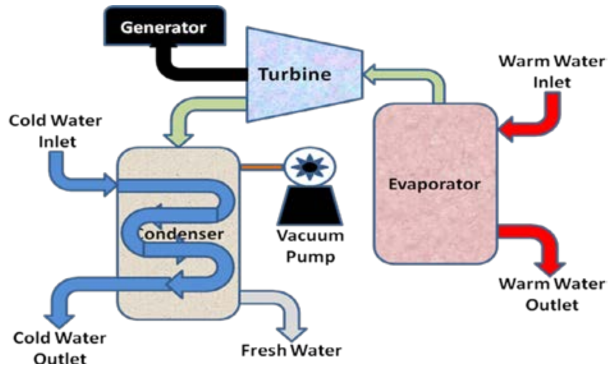


Figure 1. Open Cycle

B. OTEC for Closed Cycle

Closed-cycle systems use fluid with a low boiling point, such as ammonia, to rotate a turbine to generate electricity. Warm surface seawater is pumped through a heat exchanger where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo-generator. Then, cold, deep seawater—pumped through a second heat exchanger-condenses the vapor back into a liquid, which is then recycled through the system, as shown in Figure 3.

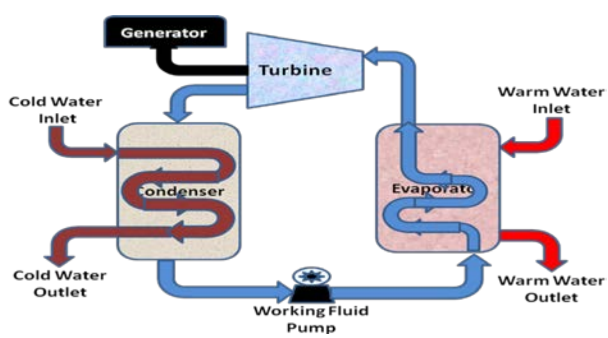
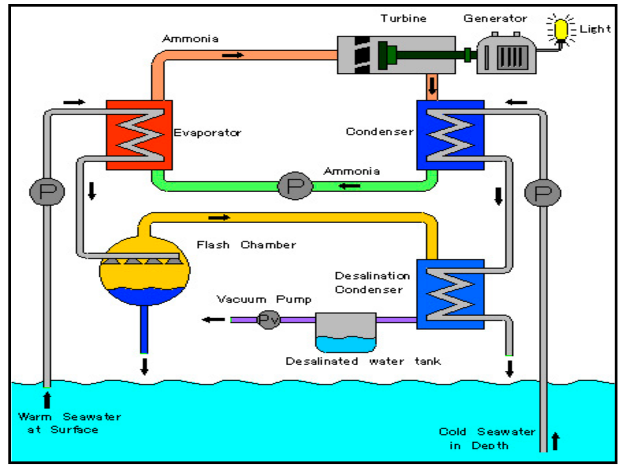


Figure 2. Closed Cycle

C. OTEC for Hybrid System

A hybrid cycle combines the features of both the closed-cycle and open-cycle systems. In a hybrid OTEC system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, similar to the open-cycle evaporation process. The steam vaporizes the ammonia working fluid of a closed-cycle loop on the other side of an ammonia vaporizer. The vaporized fluid then drives a turbine to produce electricity. The steam condenses within the heat exchanger and provides desalinated water. Flow diagram of hybrid system shown in Figure 3.



Courtesy: Y. Ikegami

Figure 3. Flow Diagram of Hybrid system

II. PROBLEM FORMULATION

Indonesia is the tropical oceans country, approximately defined by latitudes less than 20 degrees, may be thought of as enormous passive solar collectors, and the amount of available OTEC energy has often been evaluated on the basis of how much solar radiation is absorbed by the upper layer of the oceans. This method is flawed in many respects: for example, a strictly renewable OTEC resource should be limited by the supply of deep cold seawater from the polar regions; it also leads to extraordinarily optimistic (large) numbers, with convertible energy in one 1-degree-by-1-degree mesh element of a latitude-longitude grid amounting to the electricity production of a large developed country (say 5 quads, or 5 x 10^{11} kWh, per year). More sober estimates are typically three orders of magnitude smaller, but still represent a potential resource globally comparable to the World's current electricity output.

Problem Solution

A survey of suitable OTEC power plant locations shows that temperature difference large enough for OTEC, approximately correspond to latitudes less than 20 degrees.

That arguments make it clear that Indonesia, a country of 1.9 million km^2 stretching from latitudes 6º08' N to 11º15' S and longitudes 94º45' E to 141º05' E, globally has excellent and potentially significant OTEC resources. Moreover, the great number of islands included in the Indonesian archipelago define a sea area about four times larger than the country itself, on the basis of a 200-nautical-mile Exclusive Economic Zone (EEZ) as number third in the world.

The development of OTEC resources is also critically dependent upon the accessibility of the deep cold seawater heat sink, i.e. on the steepness of the coastal seafloor. Coincidentally, a rapidly dropping seafloor often corresponds to excellent wave power resources as well. Sea depths around southern Sumatera, Java and eastern Indonesia quickly exceed 1,000 m as one moves away from shore. In some areas, a depth of 500 m is reached within only 2 km from the coastline. Global Indonesian bathymetric features are shown in Figure 4.

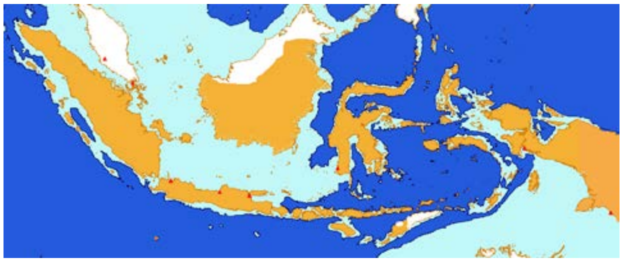


Figure. 4. The steepness (■ 1,000 m or more depth) of the coastal seafloor of Indonesia as OTEC resources

The absence of typhoons in Indonesia is a very positive point, since the OTEC resource often position in regions of active tropical storms. In other countries, such as the Philippines, the frequent occurrence of violent typhoons represents a major hurdle to the deployment of OTEC plants, whether on platforms (with delicate connections between platform and cold water pipe, or between platform and power cable) or on land, in the path of storm surges.

Indonesia is a country of active volcanism, however: earthquakes and tsunamis consequently may happen. Such events are very rare, though they are potentially violent, as historical records show. OTEC plants deployed on floating platforms would definitely be spared from earthquakes or tsunamis. Land-based plants can be designed with state-of-the-art guidelines, and should only suffer major damage during the most catastrophic events, i.e. when it could be argued that virtually no structure on land or near the shoreline would be safe from destruction, thus, it may be unreasonable to rule out OTEC plants in those areas without ruling out any industrial infrastructure at all.

The temperature of surface seawater around Indonesia water in all year mostly between 29 – 31 ºC as shown in Figure 5, and candidate OTEC of temperature difference more than 20 ºC in Western of Sumatera found at depth between 500 – 800 meter.

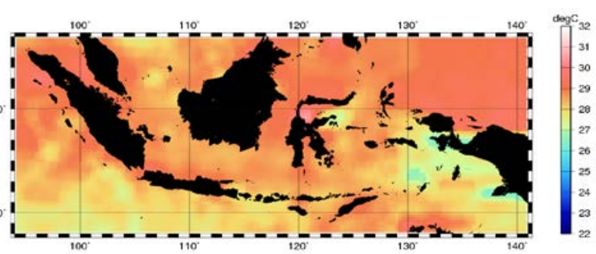


Figure.5. Sea surface temperature

Advantage for OTEC plant:

- OTEC uses clean, renewable, natural resources. Warm surface seawater and cold water the ocean depths replace fossil fuels to produce electricity;
- Suitably designed OTEC plants will produce little or no carbon dioxide or other polluting chemicals;
- OTEC systems can produces fresh water as well as electricity. This is a significant advantage in island areas where fresh water is limited;
- There is enough solar energy received and stored in the warm tropical ocean surface layer to provide most, if not all, of present human energy needs;
- The use of OTEC as a source of electricity will help reduce the state's almost complete dependence on imported fossil fuels.

Disadvantage for OTEC plant

- OTEC-produced electricity at present would cost more than electricity generated from fossil fuels at their current costs.
- OTEC plants must be located where a difference of about 20 ^{0}C occurs year round. Ocean depths must be available fairly close to shore-based facilities for economic operation. Floating plant ships could provide more flexibility.
- No energy company will put money in this project because it only had been tested in a very small scale.
- Construction of OTEC plants and lying of pipes in coastal waters may cause localized damage to reefs and near-shore marine ecosystems.

II. Estimation of Potential of OTEC in Indonesia

Indonesia has coastlines totaling 95,181 km in length making it the country with fourth longest coastline in the world, based on The United Nations (UN) announced in 2008.

Length of coastline of Indonesia : 95,181 km

Potential OTEC about 70% of coastline of Indonesia: 0.7 x 95,181 = 66,627 km

Distance between 100 MW OTEC plant : 30 km

Estimation OTEC potential in Indonesia :

[66,627 / 30] x 100 MW = 222,089 MW = 222 GW of electricity

Capacity factor (CF) of OTEC to produce electricity a year is 0.8 that mean

OTEC has potential about:

0.8 x 24 x 365 x 222 GW = 15,557,760 GW_h or 15,557 TW_h.

Indonesia Overview

The Republic of Indonesia is a country in Southeast Asia. Indonesia comprises 17,508 islands, and with an estimated population today (2015) of around 245 million people, it is the world's fourth most populous country, and has the largest Muslim population in the world.

Indonesia consists of 33 provinces, five of which have special status. Each province has its own political legislature and governor. The provinces are subdivided into regencies (*kabupaten*) and cities (*kota*), which are further subdivided into sub districts (*kecamatan*), and again into village groupings (either *desa* or *kelurahan*). Following the implementation of regional autonomy measures in 2001, the regencies and cities have become the key administrative units, responsible for providing most government services. The village administration level is the most influential on a citizen's daily life, and handles matters of a village or neighborhood through an elected *lurah* or *kepala desa* (village chief).

The provinces of Aceh, Jakarta, Yogyakarta, Papua, and West Papua have greater legislative privileges and a higher degree of autonomy from the central government than the other provinces. The Acehnese government, for example, has the right to create an independent legal system; in 2003, Yogyakarta was granted the status of Special Region in recognition of its pivotal role in supporting Indonesian Republicans during the Indonesian Revolution. Papua, formerly known as Irian Jaya, was granted special autonomy status in 2001. Jakarta is the country's special capital region.

Population

Over 200 years, the population of Indonesia has steadily grown from 18.3 million in 1800 to 40.2 million in 1900, to 205.8 million in 2000. Over the past fifteenth years, the population went up from 205 million to 245 million.

III. Potential of OTEC on West Sumatera

This study will be investigate OTEC resources on West Sumatera as candidate to develop pilot project 5 MW OTEC plant. Data for sites locations necessary to continuously looking for data in table 1.

Table 1. General Data of West Sumatera

No.	Items	Number
1.	Population	(people)
	- 2011	4,904,460
	- 2012	4,957,719
	- 2013	5,617,977
2.	Tourist Visit	(foreign country)
	- 2011	30,340
	- 2012	36,953
	- 2013	44,135
3.	Electricity Production	(Mwh)
	- 2011	2,909,200
	- 2012	3,177,200
	- 2013	3,344,600
4.	Electricity Supply	(Mwh)
	- 2011	2,403,090
	- 2012	2,649,070
	- 2013	2,788,680
5.	Water Demand	(M^3)
	- 2011	47,851,000
	- 2012	54,306,000
	- 2013	156,128,000

Source: BPS (Badan Pusat Statistik)

Location for OTEC in West Sumatera

West Sumatera position in the middle of the western coast of Sumatera, and has an area of 42,297.30 km². Geographic features include plains, mountainous volcanic highlands formed by the Bukit Barisan mountain range that runs from north-west to south-east, and an offshore island archipelago called the Mentawai Islands. The West Sumatera coastline faces the Indian Ocean and stretches 375 km from North Sumatera province in the north-west to Bengkulu in the south-east. West Sumatera is the best destination for tourism, with natural attractions of the mainland include the tropical forests, mountains, volcanoes, lakes, valleys, rivers & waterfalls in the highlands, the fauna and flora, and the beaches around Padang and Mentawai Islands a popular destination for surfers all over the world. The Mentawai Islands are a chain of about seventy islands and islets off the western coast of Sumatera in Indonesia. Siberut (4,030 km²) is the largest of the islands. The other major islands are Sipura, North Pagai (*Pagai Utara*) and South Pagai (*Pagai Selatan*). The islands lie approximately 150 km off the Sumatera coast, across the Mentawai Strait. Based on bathymetry and user of electricity and by-product of OTEC, elected 3 (three) areas in West Sumatera as candidate to develop 5 MW OTEC plant. Temperature surface and deep seawater around 3 locations on January only until depth 200 m. January is the peak of rainy season in West Sumatera, temperature surface seawater about 29 ^{0}C. Even temperature on July not available now, temperature of surface seawater on July higher than temperature on January. For more depth of seawater necessary to take new data before build OTEC plant. Temperature data at western of Siberut Island (ordinate 01 N and 97.5 E) shown until depth 1000 m. Candidate locations as shown in figure 6, and temperature of seawater as shown in table 2.

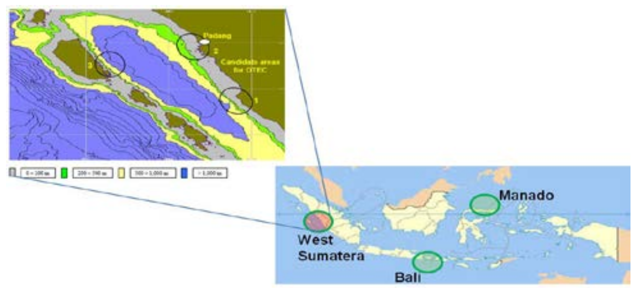


Figure. 6. Three locations as candidate for OTEC plants in West Sumatera

Table 2. Coastline Temperature on West Sumatera

Depth (m)	Mean (^{0}C)	Max (^{0}C)	Min (^{0}C)	Number of Sample	Standart Deviation
0	29.05	30.80	27.20	15	0.78
10	29.09	30.50	28.26	16	0.54
20	28.97	30.20	28.20	17	0.50
30	28.90	29.90	27.45	17	0.57
50	28.82	29.40	28.20	14	0.36
75	27.54	29.20	22.66	17	2.03
100	26.24	28.61	20.90	17	2.54
125	18.29	28.60	14.88	14	4.58
150	15.71	20.00	14.10	16	1.89
200	13.71	14.90	12.10	14	0.62
250	12.30	13.50	11.10	11	0.68
300	11.80	12.32	11.54	7	0.29
400	10.94	11.50	10.66	7	0.27
500	10.05	10.50	9.31	7	0.38
600	9.20	9.47	9.06	6	0.15

700	8.42	8.67	8.18	6	0.22
800	7.70	7.98	7.57	5	0.16
900	7.18	7.37	7.01	4	0.18
1000	6.74	7.18	6.42	4	0.36

Source: BPS (Badan Pusat Statistik)

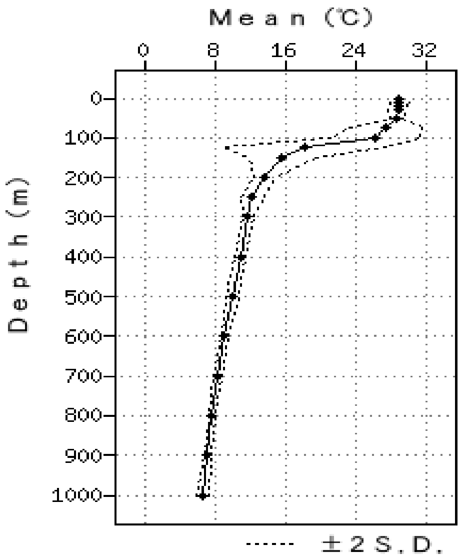


Figure. 7. Three location temperature

At western of Siberut island on depth around 600 meter, temperature difference found 20 ^{O}C, as good resources for OTEC. Others data at 3 locations can see in Table 3.

Table 3. Data of 3 candidate locations for OTEC plant in West Sumatera

	Location 1	Location 2	Location 3
City/Regency	Pesisir Selatan	Padang	Mentawai Islands
Ordinate	2.10 S /100.51 E	0.57 S /100.21 E	1.26 S /99.8 E
Population (2013)	568.520 people	871.534 people	82.355 people
Electricity & Water	- Pancung Soal city - Balai Tapan city - Baganti city - Ranah Pesiri	Padang city	Siberut Island
Sea surface temperature (^{0}C)			
- January	28.80	28.80	28.80
- July	29.01	29.01	29.01
Depth (m)	600 to 700	600 to 700	600 to 700
Distance from coastline	12 km	18 km	10 km
History of			
Typhoon	None	None	None
Tsunami	Rarely	Rarely	Rarely
Earthquake	Many	Many	Many

Source : BPS (Badan Pusat Statitik)

The future for OTEC Prospects & Innovations

We can measure the value of an OTEC plant and continued OTEC development by the economic benefits for the future is,

- Helps produce fuels such as hydrogen, and lithium
- Produces base load electrical energy.
- Produces desalinated water for industrial, agricultural, and residential uses.
- Is a resource for on-shore and near-shore marine culture operations.
- Provides air-conditioning for buildings.
- Provides moderate-temperature refrigeration.
- Has significant potential to provide clean, cost-effective electricity for the future.

5. Conclusion

Indonesia has excellent ocean thermal energy conversion technology resources, especially along southern West Sumatra is Pesisir Selatan, Padang & Mentawai Island and in Indonesia all coastline with estimation potential about 222 GW or 15,557 TW_h of electricity. And basically is the renewable and environmentally friendly OTEC resource has not yet been commercially tapped anywhere in the world.

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