JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 1, Issue No. 1 (June-2015)
ISSN: 2413-5267

Generation of Electrical Power Using Thermal Energy of Sea Water Off The Libyan Shores

Hesham G. Ibrahim[1,*], Aly Y. Okasha[1], and Mokhtar S. Elatrash[2]

[1] Faculty of Marine Resources, Al-Asmarya Islamic University, Libya.
[2] Environmental Science Department, Faculty of Science, Al-Mergheb University, Libya.
*Corresponding author: h_g_ibrahim@yahoo.com

توليد الطاقة الكهربائية بإستخدام الطاقة الحرارية لمياه البحر قبالة شواطئ ليبيا

هشام جهاد إبراهيم، علي يوسف عكاشة، و مختار سالم الأطرش

كلية الموارد البحرية، الجامعة الأسمرية الإسلامية، ليبيا.

كلية العلوم، جامعة المرقب، ليبيا

Abstract

Transformation of thermal energy of ocean/sea into power, a procedure referred to as OTEC or on the other hand as STEC, utilizes the regular temperature contrast between the upper water layers temperature and close sea bed layers temperature to work through a thermodynamic cycle. This paper displays a study on a conceivable use of Mediterranean waters off the shores of Zliten city in northwest Libya utilizing this innovation. This study concern to design and simulation of a thermodynamic cycle operating at steady state conditions based on actual climatic data by using Aspen-Hysysv7.3. Results indicated that a closed loop thermodynamic cycle can offer a potential source of renewable energy, and the resulting design data of heat engine used to transform thermal energy into electricity is a feasible, and an efficient approach to generate about 25 *MW* of electrical power at negligible ecological risks.

Keywords: *Renewable energy, Aspen Hysys, Off Shores, Zliten, Rankine cycle.*

الملخص

تحويل الطاقة الحرارية للمحيطات/البحر إلى طاقة كهربائية، تعرف بـOTEC أو تعرف بـSTEC، حيث يُستخدم التباين في درجة الحرارة بين طبقات سطح المياه العليا مع درجات حرارة طبقات المياه العميقة في توليد الطاقة من خلال إستخدام الدورة الحرارية. تعرض هذه الدراسة إمكانية استخدام هذه التقنية في مياه البحر الأبيض المتوسط قبالة شواطئ مدينة زليتن في شمال غرب ليبيا. تركز هذه الدراسة على تصميم ومحاكاة الدورة الحرارية التي تعمل في ظروف مستقرة استنادا إلى البيانات المناخية الفعلية باستخدام برنامج المحاكاة أسبن–هايسيس الإصدار 7.3. أشارت النتائج إلى أن دورة الحرارية المغلقة يمكن أن تقدم مصدرا محتملا للطاقة المتجددة، وبيانات التصميم الناتجة من حرارة المحرك المستخدمة لتحويل الطاقة الحرارية إلى طاقة كهربائية هي عمليه وفعالة في توليد حوالي 25 ميجاوات من الطاقة الكهربائية دون حدوث أي مخاطر تُذكر على البيئة.

الكلمات الدلالية: طاقة متجددة، أسبن هايسيس، الساحل الليبي، زليتن، دورة رانكن.

1. Introduction

Solar energy absorbed by the oceans and seas is equivalent to 4000 times the present world consumption of energy. Oceans and seas cover more than 70% of the earth surface, which make them the largest solar energy collector and energy storage system on earth. Sixty million square kilometers of tropical seas absorb an amount of solar radiation equal in heat content to about 29 billion kilolitres (250 billion barrels) of oil (Vega, 1995; SOPAC, 2001).

Heat stored in ocean and sea waters can be converted into electricity by means of a technology known as Thermal Energy Conversion OTEC or alternatively as STEC, which uses the water natural temperature gradient to drive a turbine connected to a generator which produces electricity. D'Arsonval proposed use of the relatively warm surface water (24 *°C* to 30 *°C*) of the tropical oceans to vaporize pressurized ammonia through a heat exchanger (i.e., evaporator) and use the resulting vapor to drive a turbine-generator (Vega, 1995). The cold water transported (upwelled) to the surface from depths of sea, with temperatures ranging from 8 *°C* to 4 *°C*, would condense the ammonia vapor through another heat exchanger (i.e., condenser). The concept is grounded in using a Rankine cycle and deployment of ammonia as a working fluid.

The proposed STEC technology offers several potential environmental benefits. It is a source of clean, renewable and unlimited energy and its use ensures a reliable and constant power output independent of any climatic conditions. Furthermore, STEC does not discharge any CO_2 and deep water mixing with the upper layers of the sea helps to grow phytoplankton, algae and coal which may lead to an increased CO_2 fixation. Environmental concerns associated with STEC underlay in using harmful working fluids such as ammonia or chlorine that could leak into the sea water if pipes were damaged and disruption of habitat in the sea due to the installation of pipes (Takahashi, and Trenka, 1996). However, such impact can be reduced or avoided through improved designs, further research (Finney, 2008).

The main objective of this paper is to assess to possibility of converting sea thermal energy into electrical power by using the natural temperature gradient of the Mediterranean sea off the Libyan coast by using the average climatic data of five years recorded at the offshore station to the north of Libya at Zliten city as a renewable source of energy.

2. Sea Thermal Energy Conversion cycles

STEC process is a renewable energy technology designed to transform thermal energy into electricity. A STEC cycle is driven by temperature difference between warm surface waters and cold deep waters of sea and deploys a low specific heat working fluid. A desirable temperature difference between warm surface waters and the cold deep waters is 15 ^{o}C (Vega, 1995; and Twidell & Weir, 1994). In general there are three basic types of systems that can utilize sea water temperature differentials, closed-cycle system, Open-cycle system and Hyperd cycle system (SOPAC, 2001; Takahashi & Trenka, 1996; and Thomas, 1993). The

ISSN: 2413-5267

characteristics of each cycle are detailed by (SOPAC, 2001; Francis & Dugger, 1980; NOAA, 1981; and Avery, 1985).

3. Design Considerations

A heat engine can take the form of a closed-cycle process which employs a working fluid (e.g., ammonia) that converts into vapor exchanges heat with warm seawater. The expanding gas drives a gas turbine then re-condenses by cold seawater, and the process is repeated as given by (Myers et al., 1986). The advantages of using a closed-cycle system are that it is more compact than an open-cycle system and can be designed to produce the same amount of power using already existing turbo machinery and heat exchanger designs. Therefore the proposed design is a closed cycle.

3.1 Plant Characterization

A closed-cycle type using ammonia as a working fluid can be designed in various sizes. Smaller plants of a pilot-plant scale can probably be located on or near shores or submersed and mounted towers about 100 *m* below water surface, where larger plants of a commercial scale can either be based on bottom-mounted towers or offshore in a form of moored floating plants or free floating plant ships.

Proposed plants are made up of multiple units operate independently. A typical pilot plant can be made up of four to six 10 *MW* units, while eventually ten to twenty 25-*MW* units can be typical for commercial plants (Avery & Wu, 1994).

Pilot plants located on or near shore where space is not particularly limited have horizontal dimensions on the order of 100 *m*. Bottom-mounted plants (on towers) makes use of the space along the vertical extent of the tower and thus their horizontal dimensions are on the order of 50 *m*. Larger plants (commercial scale) in the open sea (ocean) are proposed to be within 100-150 *m* in diameter for cylindrically symmetric designs and 50-75 *m* wide×150-200 *m* long for on ship or barge type designs.

3.2 Power System

Most first-generation STEC plant designs specify ammonia as the working fluid, and successfully tested heat exchangers at small scale are tube/shell and folded tubes types fabricated of aluminum or titanium (Avery & Wu, 1994).

Daily Chlorination and mechanical cleaning in conjunction with chlorination are known for biofouling control. The dose of chlorine needed to prevent biofouling depend on site specific characteristics; however, recent studies suggest that doses on the order of 0.07 *mg/l* (70 *ppb*) injected 1 *hr/day* may be sufficient (Larson-Basse & Daniel 1983).

3.3 Seawater System

3.3.1. Warm Water Intake

Proposed warm-water intake is in the upper part of the surface mixed layer of the sea to take advantage of the warmest water available. Intakes for pilot plants is about 10 *m* deep, while intakes for larger commercial plants is about 20 *m* deep due to the larger intake flow-rate requirements.

It is suggested that intake structure be constructed to produce horizontal flows external to the structure as it appears that fish can sense and avoid horizontal flows better than vertical flows. The structure should be much larger in the horizontal direction than in the vertical direction to keep intake velocities low and yet keep the structure near surface where the warmest water is located.

Typical warm-water flow rates for STEC designs are in the range of 3-5 $m^3/sec.MW$. However, flow rates as high as 8.5 $m^3/sec.MW$ are proposed for plants trade larger flow rates for less expensive heat exchangers. Flow velocities in the warm-water pipes and conduits are in the range of 1.5-2.5 *m/sec*, but intakes are expected to be designed to reduce velocity to 0.25-0.30 *m/sec* outside the intake structure. The low intake velocities can lead to rather large intake area requirements for large plants (i.e. 100 *MW*).

3.3.2. Cold Water Intake

Cold-water intake for most STEC designs at the end of a long pipe extending to a depth is decided as a trade-off between the efficiency gained by colder temperatures and the added expense of constructing and operating a longer cold-water pipe. The pipe length is normally within 750 and 1000 *m*. Since cold-water intake is to be located at a depth of a low biological activities, little effort is needed for the intake structure design and an open ended pipe with bar screens to keep out large objects is probably sufficient.

Typical STEC designs call for coldwater flow rates comparable to warm-water flow rates, in the range of 3-5 $m^3/sec.MW$. However, reduction of cold-water flow rates from depth can be significant in reducing expenses. Flow velocities in the cold-water pipe are generally within 1.5-2.5 *m/sec* range. Intake velocities may be of the same order as there is no need to reduce the intake velocity at great depths, however, lower intake velocities can be achieved, if needed, by using a flared pipe section. It is reported that 0.3 *m/sec* intake velocity is achievable (Myers et al., 1986).

3.3.3. Discharge

It is significant to locate the discharge so as to reduce the potential for recirculation of effluent into the warm-water intake. Although this may be accomplished through either separate or mixed effluent discharges, most designs depend on the density of the effluent being greater than the density within the mixed layer so that the effluent can come to equilibrium near the bottom of the mixed layer, out of the influence of the intake. For near shore plants this may

ISSN: 2413-5267

involve the use of a discharge pipe leading offshore. In deeper waters it is suggested that discharge at a depth of 30 *m* or greater to avoid recirculation is sufficient. It is also suggested that warm and cold water temperatures change about 2-3 °*C* during passage through the heat exchangers. For representative warm and cold waters of 25 °*C* and 5 °*C*, respectively, temperatures of separate warm and cold discharges would then be about 23-22 °*C* and 7-8 °*C*, respectively. In this situation, a mixed discharge would have a temperature near 15 °*C*.

Most proposed designs do not involve the use of any special discharge structures such as multiport diffusers. Thus, discharges can be open-ended round pipes directed either downward or horizontally (often with a downward component).

Discharge flow rates and intake flow rates are equal due to continuity and typical discharge velocities are within 1.5-2.5 *m/sec* range.

4. Simulation of Designed Cycle

Aspen-Hysys simulation of a proposed 25 *MW* electric power STEC closed cycle (Figure 1). The main fluids using sea water and ammonia as dynamic fluids as in accordance with the specification mentioned previously.

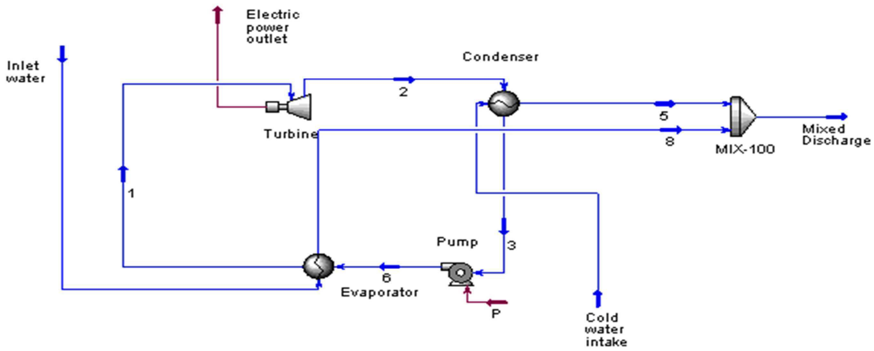

Figure 1. Simulated STCE (closed cycle)

Average monthly temperatures of surface sea (temperature of inlet water to evaporator) at the proposed in the Mediterranean sea north of Zliten City are given in Table (2).

Table 2. Average monthly sea water surface temperatures near Zliten city (NCCC, 2013).

Month	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*
Temp. (^oC)	**17.5**	**17.2**	**17.2**	**17.5**	**19**	**22**	**25**	**27**	**26**	**24**	**22**	**19**

Sea water temperature at a depth of 500 *m* and 12 *km* from the shore is 4 ^oC (Jagusztyn & Reny, 2010).

ISSN: 2413-5267

5. Results and Discussion

Variation of the surface and depth temperatures of sea water, and flow rates of inlet and outlet sea water and working fluid (ammonia) are shown in Table (3). The simulation process of the proposed cycle reveals that a power output of 25 *MW* is an achievable target a closed cycle taking into account the actual climatic conditions at the proposed region as detailed in Table (3). A temperature difference of 5 ^oC between incoming water and outgoing water temperatures at the inlets and outlets of the condenser and evaporator of the open cycle design is essential to generate 25 *MW* throughout the day. The climatic data at the proposed region indicate the difference between sea water surface temperature and water temperature at the bottom exceeds 15 ^oC throughout most of the year (from May until December) and exceeds 13 ^oC during January through April, which makes the project economically attractive (Twidell, and Weir, 1994). Generally, the temperature difference between the upper (warm) and bottom (cold) water layers ranges from 10 °*C* to 25 °*C*, with the higher values found in equatorial waters (Vega, 1995).

The evaporator and the condenser are designed in accordance with the British standard institute (BS 3274). Design specification needed to a power output of 25 *MW* are provided in Table (4).

6. Conclusion

Sea Thermal energy conversion (STEC) is a potential source of renewable energy. The main advantages of closed STEC cycle design are fuel free at a low environmental impact, and such project can supply pure water for house use and agriculture, and can supply refrigeration and cooling (Finney, 2008; and CRRC, 2009). Results of simulation show that (heat engine) designed to transform thermal energy into electricity is a feasible, and an efficient approach to generate electricity from the Mediterranean sea water 12 *km* off the Libya coast north of Zliten city.

ISSN: 2413-5267

Table 3. Variation of average monthly sea water surface temperature and their effect on electric power output

Units / Month	Cycle	Evaporator Flow rate kg/hr	Evaporator In °C	Evaporator Out °C	Condenser Flow rate kg/hr	Condenser In °C	Condenser Out °C	Power generated MW	Power consum. MW
Jan.	***Water cycle***	$7.787*10^8$	17.5	12.5	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Feb.	***Water cycle***	$7.787*10^8$	17.2	12.2	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Mar.	***Water cycle***	$7.787*10^8$	17.2	12.2	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Apr.	***Water cycle***	$7.787*10^8$	17.5	12.5	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
May	***Water cycle***	$7.787*10^8$	19	14	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Jun.	***Water cycle***	$7.787*10^8$	22	17	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Jul.	***Water cycle***	$7.787*10^8$	25	20	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Aug.	***Water cycle***	$7.787*10^8$	27	22	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Sep.	***Water cycle***	$7.787*10^8$	26	21	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Oct.	***Water cycle***	$7.787*10^8$	24	19	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Nov.	***Water cycle***	$7.787*10^8$	22	17	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		
Dec.	***Water cycle***	$7.787*10^8$	19	14	$7.736*10^8$	4	9	25	1.172
	Ammonia cycle	$1.331*10^7$	12.1	16	$1.331*10^7$	12.1	12.06		

Table 4. Heat Exchangers Design data for 25 *MW* STEC plant

Configuration	Design data	Unit	Data	
			Condenser	**Evaporator**
Overall	No. of shell	--	1	2
	Tube passes per shell	--	2	2
	1st tube pass flow direction	--	counter	Counter
	Elevation (base)	--	0	0
	Heat transfer area per shell	m^2	60.32	37.7
	Tube volume per shell	m^3	0.193	0.1206
	Shell volume per shell	m^3	2.272	36.76
Shell	Shell diameter	*mm*	739.05	2800
	No. of tubes per shell	--	160	100
	Tube pitch	*mm*	50	50
	Tube layout angle	--	Triangular (30 ^{o})	Triangular (30 ^{o})
	Shell baffle	--	Single	Single
	Shell baffle orientation	--	Horizontal	Horizontal
	Baffle cut	*Area %*	20	20
	Baffle spacing	*Mm*	800	800
Tubes	OD	*Mm*	19	19
	ID	*Mm*	16	16
	Length	*M*	6	6
	BWG	--	16	16

References

Avery W.H. & Wu C. (1994). *Renewable Energy from the Ocean*. Oxford University Press, New York.

Avery W.H., Richards D., & Dugger G.L. (1985). Hydrogen generation by electrolysis, and economical energy transfer to world markets via ammonia and methanol. *Int. J. Hydro. Energy*, 10(11): 727-736.

CRRC "Coastal Response Research Center" (2009). Technical Readiness of Ocean Thermal Energy Conversion (OTEC). *National Oceanic and Atmospheric Administration,* National Ocean Service, Office of Ocean and Coastal Resource Management, University of New Hampshire.

Finney K.A. (2008). Ocean Thermal Energy Conversion. *Guelph Engineering Journal*, (1): 17-23.

Francis E.J. & Dugger G.L. (1980). Promising applications of OTEC. In Proceedings *7th Energy technology conference*, U.S. Department of Energy, Washington D.C.

Jagusztyn T. F. & Reny M. (2010). Natural Cold Water District Cooling Plants Enabled by Directional Drilling. *In Road to Climate Friendly Chillers UNEP–ASHRAE Conference Sept.*

Larson-Basse J. & Daniel T.H. (1983). OTEC heat transfer experiments at Keahole Point, Hawaii. In Proceedings *Oceans '83 conference*, Paper F2-4, Marine Technology Society.

Myers E.P., Hoss D.E., Matsumoto W.M., Peters D.S., Seki M.P., Uchida R.N., Ditmars J.D., & Paddock R.A. (1986). The Potential Impact of Ocean Thermal Energy Conversion (OTEC) on Fisheries. *NOAA Technical Report NMFS,* 40: 33.

NCCC "National Center of Climate Changes" at Khoms City, Climate Data of Khoms/Zliten area, Libya.

NOAA (1981). Final environmental impact statement for commercial ocean thermal energy conversion (OTEC) licensing. *Office of Ocean Minerals and Energy, National Oceanic and Atmospheric Administration*, Washington D.C.

SOPAC "South Pacific Applied Geoscience Commission" (2001). Ocean Thermal Energy Conversion and the Pacific Islands. *SOPAC Miscellaneous Report 417*, prepared by; Rupeni Mario, South Pacific Applied Geoscience Commission, Japan.

Takahashi P. & Trenka A. (1996). *Ocean Thermal Energy Conversion*. John Wiley & Sons, Chichester.

Thomas G. (1993). An Assessment of Ocean Thermal Energy Conversion as an Advanced Electric Generation Methodology. In proceedings of the *IEEE*, 81(3).

Twidell J. & Weir T. (1994). *Renewable Energy Resources*. E & FN Spon, UK.

Vega L.A. (1995). *Ocean Thermal Energy Conversion in Encyclopedia of Energy Technology and the Environment*. John Wiley & Sons, Inc., New York.