TEMPERATURE DIFFERENCES IN THE OCEAN AT LOW LATITUDE AND BETWEEN SEA OR RIVER WATER AND AIR AT HIGH LATITUDES

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Contents

Summary

One of the significant stable renewable energy resources is ocean thermal energy, which springs out from temperature differences between warm, solar absorbing water and cooler deep water. The term OTEC (ocean thermal energy conversion) refers to the conversion of this energy for different other people's needs. This Article describes the processes of thermal energy accumulation in the World Ocean waters and presents the thermal energy resources for deep ocean water application. It presents estimates of ocean thermal energy stocks at low latitude, Polar regions and active zone of ocean bottom and also shows main directions of ocean thermal energy usage for humanity.

1. Thermal Energy Accumulation

The Sun annually sends to the Earth more than 2000 EJ of energy. A part of the solar radiation is reflected by clouds, absorbed by the atmosphere and the balance (about 160 W m^{-2}) arrives as an average to the Earth surface. Occupying about 71 % of the Earth surface, the oceans receive the main part of solar energy entering our Planet. The distribution of solar energy across the

Earth surface is not uniform - its major part belongs to the equatorial regions and the lesser one to polar zones. In steady state conditions, all the solar energy arriving to the ocean surface is spent for evaporation, is emitted to space by radiation and convection and a part of it is converted into air moving in the atmosphere as well as circulation of World Ocean waters.

There is a close interaction between the Ocean and atmosphere, as a result of which a portion of thermal energy is converted into atmosphere kinetic energy. On the other hand this energy returns back to the ocean in the form of wave energy and energy of streams. As far as specific thermal capacity of water exceeds about four times that of air, and the mass of water is 270 times more, the thermal energy accumulated in water is much more than in air.

Solar radiation arriving to the water surface penetrates according to water transparency to some depth and is gradually absorbed. In turbid waters more than 90 % of radiation is absorbed and converted to heat at the depth of some 10 m; in more transparent waters the solar radiation penetrates to depth of several tens of meters. The heat penetrates even deeper due to water mixing and turbulence. Particular severe mixing is observed during storms and passage of typhoons.

Moreover evaporation from the surface layer cools it down, its density becomes higher and as a result, the surface layer is dipping providing for convective mixing. Such vertical convection motions usually take place down to the depth where the density is equal to the surface layer density. From here the water density begins to grow sharply. Such a layer is named as the layer of density jump or picnocline. It is a type of a partition (barrier), which is retarding the mixing and mutual energy exchange of water layers.

The thickness of uniformly mixed upper ocean layer depends on geographical region, season, force of wind as well as picnocline depth. In the ocean it may be as great as 50-200 m. But there are some cases when the mixed water layer extends from the surface to depths of few hundred meters. In the ocean under the mixed layer there is a layer of temperature jump labeled as thermocline, which usually coincides with the picnocline layer. The water temperature in this layer is sharply dropping by several degrees along only few meters. Below this layer the water temperature decreases considerably slower, reaching about 4^0C at depth of some 1000 m.

The thermocline layer plays a very important role in physics and biology of the Ocean. It also is very important for many human activities, connected with the Ocean. In particular it is of paramount importance for the use of ocean thermal energy. This layer happens to be a rather narrow boundary area between the warm water of mixed layer and much more cold waters, which are situated below.

1.1. Types of Thermal Stratification

All types of vertical water temperature differences (TD) are usually divided into three kinds. The first kind includes equatorial-tropical, tropical, eastern-tropical and sub-tropical types. This kind is specific for low latitudes, where vertical gradients exist between surface and intermediate waters.

More deep the temperature gradient is much less. Such stratification derives from strong overheating of surface waters. The temperature versus depth plots for all thermal stratification types of this kind demonstrate a well developed thermocline and differ from one another only slightly being close to the tropical type (Figure 1, curve 1).

Rather similar to the first kind is the original by-Mediterranean type (curve 2), which is produced by Mediterranean and Red Sea waters carried over to the ocean. The maximum temperature in this case is much less.

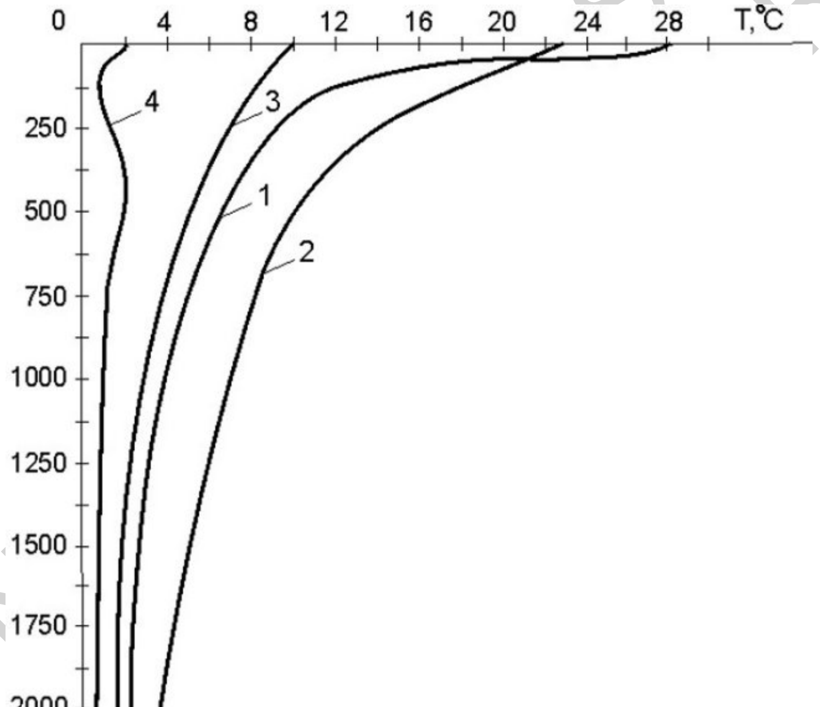

Figure 1. Types of vertical temperature distribution:
1 - tropic; 2 - Mediterranean; 3 - Atlantic; 4 - arctic

Atlantic-Pacific and Subpolar types of thermal stratification belong to the second kind. They exist in temperate and subpolar zones (Figure 1, curve 3).

In these regions because of heat exchange between ocean and cold atmosphere, the surface waters are becoming cool and convection development is increasing.

Moderate warming of water along with convection mixing provide for weak thermal stratification and rather small vertical temperature gradients.

The third kind of temperature stratification is inherent for Polar zones, it has under-surface minimum and intermediate maximum of temperature (Figure 1, curve 4).

A very weak stratification is observed for this type.

1.2. Local Vertical Temperature Distribution in the Surface Layer

Temperature distribution in tropical and equatorial zones practically does not change all-the-year-round. At subtropical latitudes some changes occur in the surface part of the temperature profile.

For example, when elaborating a combined OTEC for the Okinoerabu Island (Japan, 27^o north) ocean temperature profiles were examined at the defined site (Figure 2). The curves display seasonal variations in the range of 8^{o}C.

At moderate latitudes the thermocline shape is considerably subjected to seasonal alterations. As for the northern hemisphere the local ocean heat content becomes maximum in August (Figure 3).

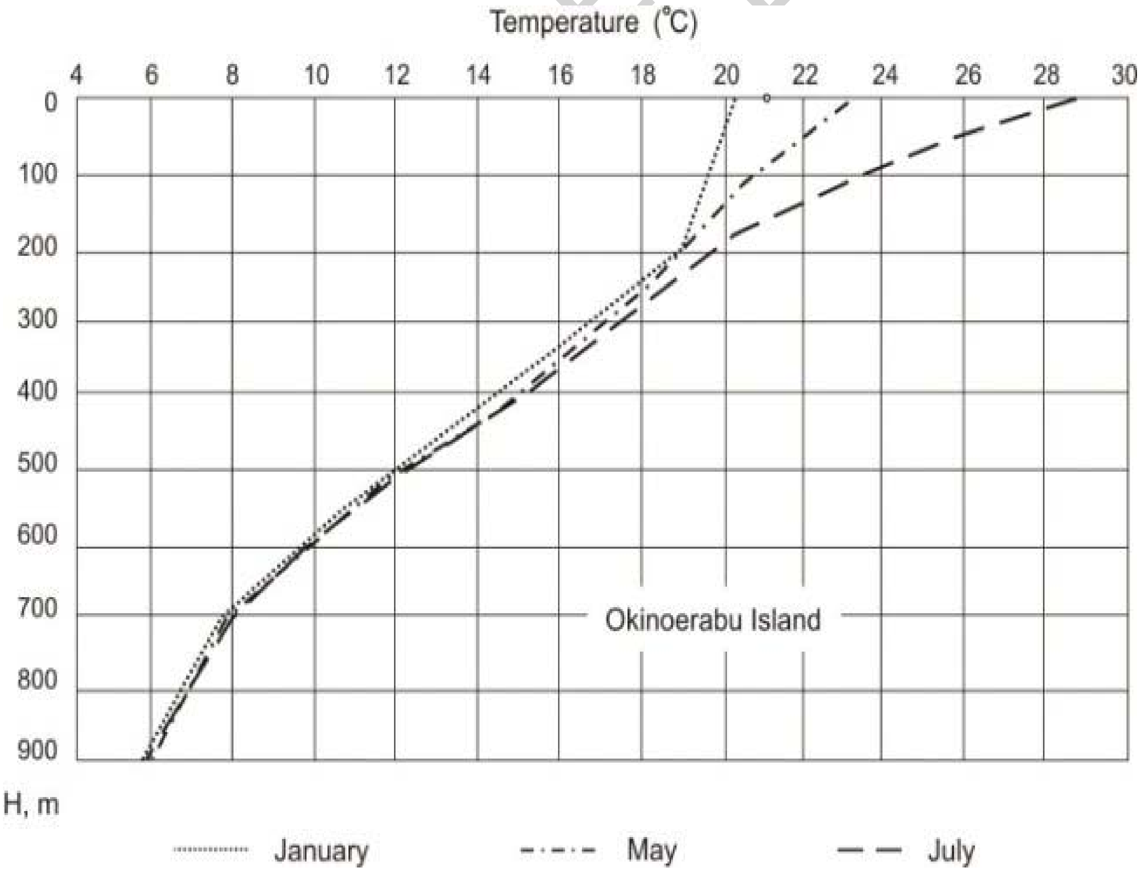

Figure 2. Tropical temperature profile variations. (Okinoerabu Island).

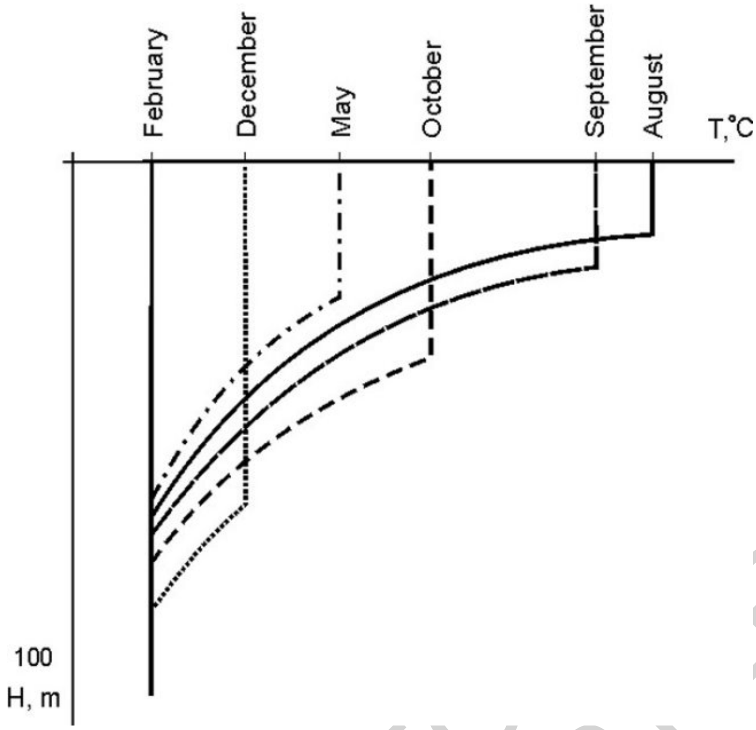

Figure 3. Annual temperature profile variations

The heat is mostly concentrated in the surface layer; its homogeneous structure is determined by the acting of windy disturbance, currents and by vertical convection during nighttime. During following months insolation is decreasing, the temperature of ocean becomes higher than air temperature. As a result of evaporation the surface layer cools down, its density growth, which in turn produces prolonged vertical convection. These waters reach the thermocline and gradually destroy it (Figure 3). By winter the thermocline do vanish down to depths, where the water density is equal to that at the surface, where it is determined by heat losses. By February the thermocline disappears completely. At high latitudes surface waters sinking in the absence of thermocline can occur down to depth of several kilometers. There are some zones in the ocean, where such deep water sinking takes place steadily. For example, there are regions in the North Arctic Ocean, where increase of water salinity and hence density generated by freezing of a part of water causes its sinking.

1.3. Abyssal Circulation

At these zones the cold water is slowly sinking, at a speed of about 36 m h^{-1} and is propagating in horizontal direction filling deep caves of the World Ocean. About 70 % of all World Ocean water content has temperature below 4^oC. At depth of 4000 m the temperature of ocean water is constantly in the range from –0.5 to $+2^oC$. A tremendous mass of World Ocean water (about 10^9 km^3) is permanently descending in areas where cold water is formed, and then it is moving horizontally towards low latitudes, here slowly ascends and at least is joining the streams of under-surface circulation. In this way the whole cycle of ocean water circulation takes place, which is the main element of climate thermal regulation.

One of theoretical schemes describing abyssal oceanic circulation was proposed by an American scientist Stommel. From two main sources at the regions of Greenland (North Atlantic) and in the Waddell Sea (the Southern Ocean) abyssal waters are mixing at the depths of 4000 m and proceed their meridian movement in the direction determined by the Earth rotation. This process can be considered as like a thermal machine, carrying ocean water from the heat source - the surface layer in the tropics down to the heat sink in zones of abyssal waters formation. Due to evaporation, radiation and convection losses ocean water lose approximately the same quantity of heat as it receives from solar radiation, maintaining steady thermal condition of ocean.

The World Ocean is the largest natural solar energy storage. In the tropical zone maximal temperature differences (about 20^{o}C) exist between warm, absorbing solar radiation surface waters and colder by-bottom waters. This temperature difference can be regarded as a continually renewed source of environmentally clean thermal energy, which can be transformed in other kinds of useful energy.

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Bibliography

Akulitchev A., Ilyin A. (1987). *Renewed resources of ocean energy*. Proceeding of Pacific Oceanology Institute RAS. Vladivostok (in Russian). [Opportunities of creation of converters for OTEC and AWTEC plants are considered; the estimates of renewable ocean resources in Tropic and Arctic regions are given]

Golmen L., Cushman-Roisin. (1999). *Energy from seawater: A self - sustained diffusive pump*. IOA News letter, Vol. 10, No.3. [Energy resources of the temperature difference between surface and deep water in Norwegian fjord are analyzed]

Gorlov A. (1999). *Russian Experience in the ocean energy projector*. Proceeding of the IOA'99. [New theoretical and experimental works in the field creation underwater ocean units using of current and hydrothermal energy are considered]

Iceberg Utilization (1978). *Proceeding of the First International Conference*, Pergamon Press [Opportunities of creation OTEC plants on the base of temperature difference between surface warm water and cold iceberg are examined]

Gurvich E. (1998).*Metalliferous sediments of the World ocean*, pp.340, Moscow, Scientific World (in Russian) [In the book the information on results of hydrothermal activity and ore formation in the ocean has been summarized]

Ravindran M., Nagendro Kumar B. (1996). *Assessment of OTEC Potential and Promises for India*. IOA Newsletter, Vol. 7 No 4. [Estimates of thermal energy stocks and main theoretical /practical reasons on creation of OTEC plants in India are given]

Tanaka W., Nakakara H. (1994). *Concept development on agro-aqua production system with deep ocean water and hot spring water*. Proceeding IOA'94 vol. 5 Brighton UK. [Prospects and ecological consequences of development of GOTEC using temperature difference between land geothermal sources and deep ocean waters are analyzed]

Tayota T. (1999). *Present state and prospect of deep sea water application technology in Japan.* Proceeding of the IOA'99. [Results of research project for study of utilization of deep seawater to biological production and energy production are considered; future tasks for practical use deep ocean water application technology are given]

Vadus J.R. (1999). *Ocean technology and ocean energy in the 21 st century.* Proceeding of the IOA'99. [Technical accomplishments and some advances in ocean technology that may be applicable to development of future multi-product ocean energy and resource systems are briefly described]

Vega L. (1994). *Economics of ocean thermal energy conversion.* Proceeding IOA'94, vol. 5.Brighton. [The cost of producing electricity on several OTEC plants with credit for the desalinate water and co-products OTEC systems is estimated]

Wick G.L., Schmitt W.R. (1977). *Prospects for renewable energy from the sea.* MTS Journal, Vol. II No 6. [Methods of calculations of ocean energy stocks for different kind resource (temperature gradient, wave, current etc.) are given]

Biographical Sketch

Alexsander A.Gorlov (Ph.D) was born on June 3,1942. More than 25 years he worked in P.P.Shirshov Institute of Oceanology Russian Academy of Sciences (Moscow).He was chief pilot underwater manned vehicle "Pisces" and then he became scientific employee in this Institute. Many times he participated in oceanic expeditions with using research vessels and submersibles in different areas the World Ocean. He has built up reputation for as an expert in the field of the ocean engineering and energetics for ocean technology. For the last 18 years Dr. Gorlov is head of the Ocean Energy Group in the P.P.Shirsov Institute. He coordinated activities of the FSU leading organizations in designing of the separate ocean energy units. A new conception of ocean microenergetics is developed in the P.P.Shirsov Institute. The aim of this conception is to provide energy supply of autonomous long-term equipment for oceanic research on the base of ocean renewable energy (temperature gradients, waves, current etc). Dr. Gorlov was member of the Scientific Council for Nontraditional Energy Sources (Russian Ministry of Science & Russian Academy of Science). He is also member of International Ocean Thermal Energy Conversion Association since 1994. He has published more than 90 scientific papers and 2 books.