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Ocean thermal energy estimate in the southeastern of Caspian Sea: A numerical study

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The thermal structure of the Caspian Sea was studied using the three-dimensional ocean model COHERENS. Based on the simulation findings in winter, the season thermocline is almost non-existent with unvarying temperature to a depth of 100 m. However, this layer is reproduced in spring following its surface erosion in winter. A sturdy thermocline in summer and at the start of autumn causes a reduction of thermocline thickness. Hence, findings indicate thermal energy in the study area intensifications during summer. Moreover, on the eastern coast of the Sea, the efficiency was examined to establish an OTEC power plant.

[**Keywords*:*** Caspian Sea, thermocline, thermal energy, OTEC technology, COHERENS]

Introduction

A growing shortage of energy resources has intensified the interest in renewable alternative energy sources. This increasing effort is aimed at finding solutions to the challenges posed by extracting energy from the world's oceans since they are potential sources of renewable energy[1,2&3].

Given the immense amount of energy oceans produce, it is worthy to attempt to measure the extent of these natural processes. In some study by Isaac[4&5] and Seymour[6], the dissipation of ocean solar power was assessed. The study results show that power dissipation rates of the ocean for thermal energy and salinity are much more than waves, tides, and currents[7]. Energy from Ocean Temperature Gradients Ocean Thermal Energy Conversion (OTEC) technology is based on the belief that energy can be removed from any two thermal energy reservoirs with dissimilar temperatures[8&9]. A temperature difference as low as 20ºC could be exploited to create practical energy. Temperature variances of this extent exist between ocean waters on the surface and a depth of 1000 m in numerous parts of the world. Caspian Sea is not linked to a major ocean basin. It extends zonally from 46.6 to 54.8E and meridionally from 36.6 to 47.0N with northern, middle, and southern regions. Climate of the southern region is subtropical with warm summers and mild winters. Surface temperature in the northern region varies from below zero with ice in the winter to 25-26ºC in the summer. Southern region has temperatures that vary from 7-10ºC in the winter to 25-29ºC in the summer[10]. Furthermore, the northern region is shallow with a determined depth of about 20 m and the middle and southern regions with determined depths of 788 m and1025 m, respectively. Nearly 60% of the Caspian Sea's water mass is below 200 m in deep water. Sea is classified as a deep inland sea because of the characteristics of the thermocline structure and water circulation[11&12]. The mid-latitude geographical position has robust seasonal variations in heat and freshwater fluxes over the surface; thus, directing the obvious seasonal character of the thermal regime of the surface water layer of the Sea to 100m (Fig.1). At deeper depths, the temperature is relatively stable in regards to time and even over the vertical[13].

Southern basin has the highest surface temperature that decreases to the north. At nearly 20 to 30 m the robust thermocline has a temperature decrease of about 12ºC within a depth range of 10 m. At this depth the temperature in the deep water region below 200 m is lower in the central basin compared to the southern (Fig.2)[12].

Considering the present needs of humans to preserve underground resources and fossil fuels, it is necessary to use renewable energy. Since the southern

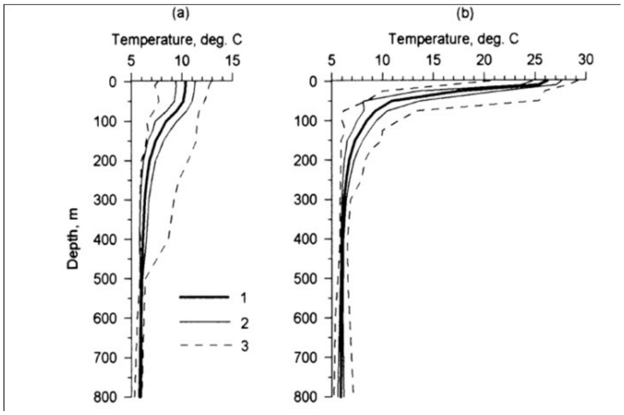

Fig. 1 — map Climatic vertical profiles of the water temperature in February (a) andAugust (b) in the deep-water area of the Southern Caspian Sea (1 Mean values, 2 standard deviations, 3 extreme values.‰ Practical salinity units)[13].

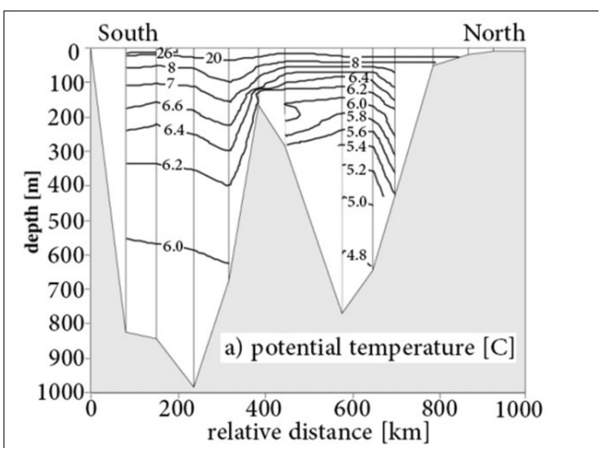

Fig 2 — Two-dimensional isopleths of potential temperature measured along the Caspian Sea from south (left) to north (right) in September 1996[12].

Caspian Sea has a relatively high water depth and the weather conditions in the region seems to be suitable to do a thermal energy study for establishing a thermal power plant, in this study we endeavored to examine the conditions to use thermal energy in this region. Hence, the aims of this research are to study the general thermal features over the seasonal cycle, and energy from ocean temperature gradients in the southern region of the Caspian Sea.

Materials and Methods

In this paper, A 3D ocean model (COHERENS)[14] in spherical coordinates was implemented over a large domain to include the Caspian Sea. The domain of this study was a rectangle and the grid resolution was 0.046° and 30 sigma layers were assumed in vertical direction. GEBCO bathymetry data with 0.5 minute resolution was used. The model is initialized in January using monthly mean temperature and salinity climatology obtained from Kara et al[15]. Model was forced by climatologic six hourly atmospheric forcing of wind velocity derived from modification of ECMWF data, air temperature and air pressure (0.5˚×0.5˚) derived from Reanalysis (ERA-Interim) ECMWF data, and precipitation rate, cloud cover (for surface radiation budget) and relative humidity (2.5˚×2.5˚) in 2004 derived from NCEP/NCAR re-analysis data. Three major rivers used in the model and the monthly mean values of the flows for the Volga (that has three locations for discharge into the Caspian Sea in the model), Ural, and Kura are used. The salinity of river water was considered to be 0‰. Monthly mean discharge value for each river was obtained from the GRDC (The Global Runoff Data Centre).

The model was run in 3D external mode with three hourly output over 5 years. Determining the amount of possible energy from the ocean thermal requires a database with temporal and spatial variation so that the data can be collected by field measurements. However, this method is costly and time consuming; hence, an alternative is a numerical model.

In this research, considering the fact that OTEC technology is based on temperature differences between seawater surface and depth, it was necessary to examine thermal profiles and thermocline. Initially the formation of the thermocline layer was studied for a year using simulation. Then by using the Carnot cycle relationship in the thermal machines, the efficiency of these plants was examined.

In the tropical regions, the surface layers warm to about 25ºC. However, the temperature in deep layers from approximately 600 m is about 5ºC. This temperature difference can be used based on thermodynamic principles to create a heat engine that produces electrical power.

Results

The findings of the simulation show surface temperature is highest in the southern region and reduces to the north[16&17].

On the other hand, considering Fig. 3, in summer the temperature of the shallow coastal waters in the southeast of the Caspian Sea was much higher than the middle region because of its low depth. Since the coastal slope in the coastal region, especially in the eastern costal area of the southern Caspian Sea is lower than other regions, in the warmer seasons the water surface of these regions have a higher temperature compared to the other areas and the temperature difference between the surface and water depth in this area is considerable (Fig. 4).

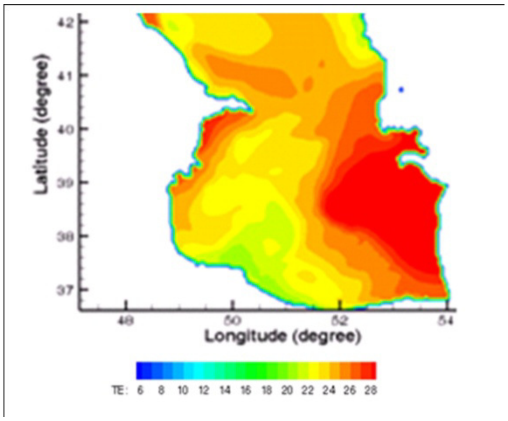

Fig. 3 — Field of the mean temperature in southern Caspian Sea during summer.

Hence, it seems to be the most suitable location to study the possibility of establishing an OTEC plant. Overall, the thermocline layer from the south to the north of the Caspian Sea in summer is between depths of 20 and 60m. In winter, the season thermocline declines noticeably and the temperature is almost down to 100 m[16].

Figure 5 shows the temperature field has resulted from simulation in 2004 in the southern Caspian Sea located at the geographical altitude 38 91˚N in the four seasons. Considering this figure, the thermocline layer structure is very weak in the winter and almost nonexistent. However, in the spring, this layer begins to reform and then in summer it develops into a very strong structure. This figure also shows that this layer in the southern Caspian Sea during the summer has been formed in a deeper region; nearly in the area less than 70 m deep from the water surface.

Since the costal slope in the coastal area, especially in the eastern coastal area of the southern Caspian Sea

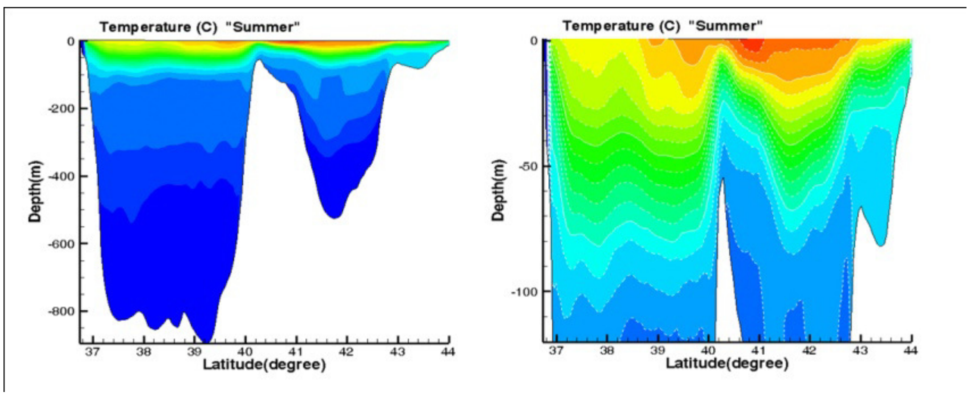

Fig. 4 — Cross-sections of the mean temperature along the Caspian Sea obtained from model simulation during summer

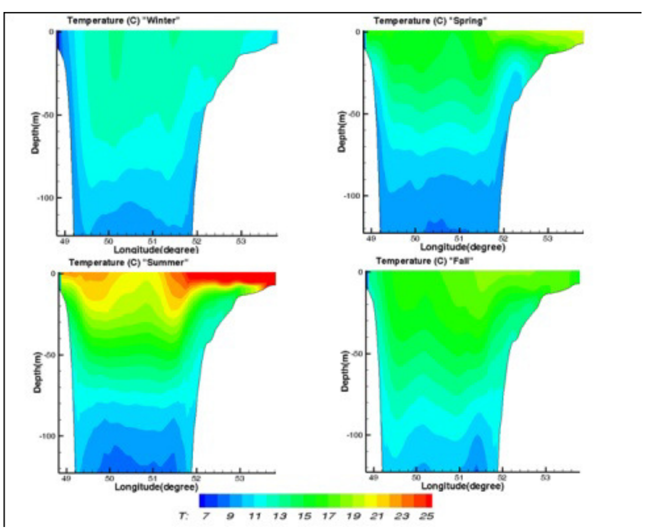

Fig. 5 — Vertical cross section of temperature (degrees Celsius) along 38 91˚N in the four seasons obtained from COHERENS simulation in 2004

is less than other regions; hence, in warmer seasons the water surface temperature in this region is higher than other areas due to the lower depth of water in the eastern coastal region of the southern Caspian Sea and the temperature difference between the water surface and the depth in this area is considerable.

This has caused the thermocline layer in this area to be formed at a closer distance to the water surface, in a way that the thermocline layer in the eastern coastal area of the southern Caspian during the summer is formed in a depth less than 25 m water surface and in the western coastal area of the southern Caspian is formed at a depth of less than 25 m.

As indicated in Fig. 5, the monthly average of the temperature field during the summer shows a significant temperature difference between the surface and depth that is more than other seasons.

In Fig. 6 the temperature field results from the 2004 simulation and has been shown for each summer month. Considering this figure, it shows that the latitude is 38 91ºN and the temperature difference between the surface layer and deeper layers (200 m) in July and September was about 20º and in August was about 20º.

Hence, based on the Carnot cycle relationship $\eta_{\max} = \frac{T_H - T_c}{T_H}$, in which $\eta_{\max}$ is the Carnot efficiency maximum, T_H is the absolute water temperature (seawater surface temperature), and T_c is the minimum water temperature (the temperature of seawater at depth). The obtained efficiency resulted in establishing an electricity production plant $\eta_{max} = 0.072$, which means about 7.2%. However, this efficiency amount was a result of ideal conditions and reaching this number is impossible due to factors such as thermal energy loss and friction. Therefore, the efficiency after these losses was about 3.5 or close to 4%, and considering the amount of energy used to pump the water, the output plant efficiency will be close to 3%. Although this efficiency seems to be low, it can be considered because it is free and is a very suitable thermal source.

For Model validation, the model results were compared with observational current and temperature data of Department of Physical Oceanography of the Iranian National Institute for Oceanography and Atmospheric Science (INIO) of Shiea et al[17&18] and Shiea and Bidokhti[19]. Generally, results from model simulations show relatively good agreement with observations. Figures 7 and 8 shows a comparison between the model output result and the field temperature data in the Anzali region in January and

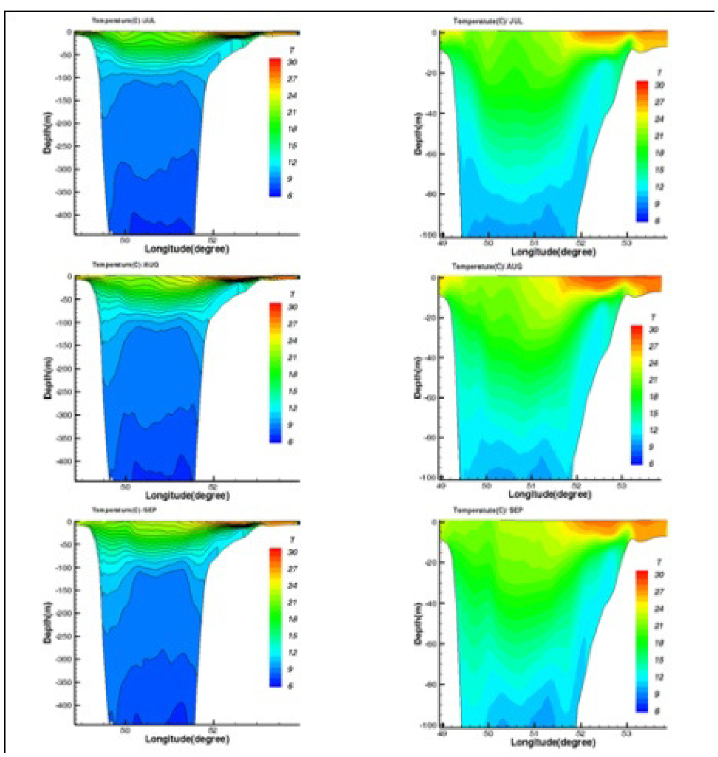

Fig. 6 — Vertical cross section of temperature (degrees Celsius) along 38 91˚N in the months of summer obtained from COHERENS simulation.

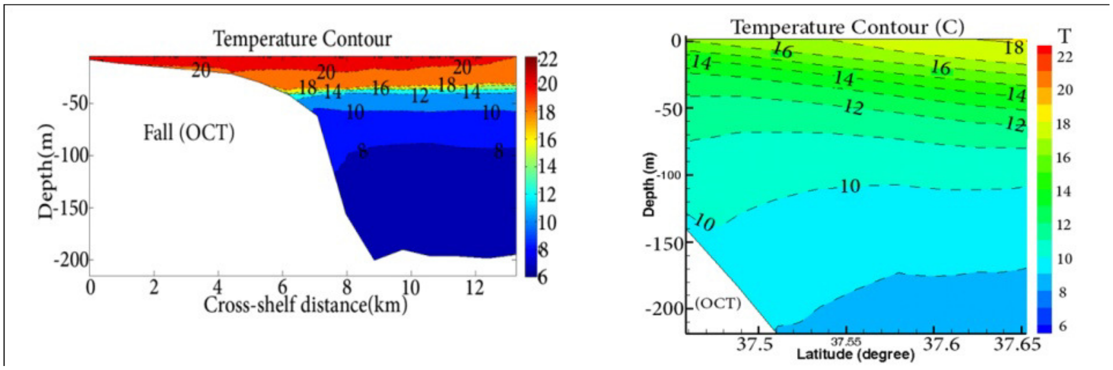

Fig. 7 — Vertical cross section of temperature (degrees Celsius) along 50°E in October obtained from observation data (above) and COHERENS simulation in 2004 (below). The square is in the field of model results.

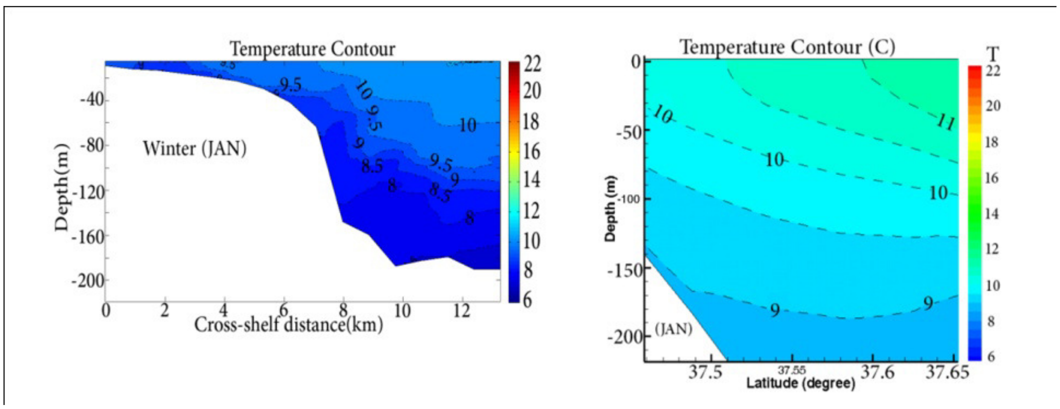

Fig. 8 — Vertical cross section of temperature (degrees Celsius) along 50°E in January obtained from from observation data (above) and COHERENS simulation in 2004 (below).

October, which indicates that the thermocline layer has been formed in a depth less than 50 m and the temperatures near the water surface are closer to eachbased on model observation and results. Also, based on Fig. 8, the thermocline layer has almost disappeared in January and the field temperature has the same amount both in the model results and observed data other based on model observation and results. Also, based on Fig. 8, the thermocline layer has almost disappeared in January and the field temperature has the same amount both in the model results and observed data.

Conclusions

The simulation results indicate that the thermocline layer structure in summer, based on the profile and temperature of vertical slices that have resulted from simulation, indicate that seasonal thermocline has formed during the summer (in contrary to winter) in the southern and middle Caspian Sea; however, in the middle Sea the seasonal thermocline layer has a slight upward inclination.

In general, the formation of the seasonal thermocline layer is in the range of 20 to 60 m from the water surface during the summer and during the winter season, the thermocline structure becomes very weak and the temperature in this season from the surface to a 100 m depth was observed as almost constant with little changes. Also, the vertical slices in the southern Caspian Sea shows that in the summer, the eastern coast of the southern Sea and the western coast of the middle Sea experienced a thermocline layer at very close distance from the water surface.

In general, the simulation results indicate that the southeastern region of the southern Caspian Sea, due to the bathymetry and atmospheric conditions increase of the water temperature of the region was more than other regions and thermocline was formed at a closer distance to the water surface. In this condition, we have an increased difference between surface and depth seawater temperatures and the Carnot cycle efficiency in this region seems to be suitable to establish an electricity production plant using OTEC technology.

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