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Determine the best location for Ocean Thermal Energy Conversion (OTEC) in Iranian Seas

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Abstract

Two-thirds of the earth's surface is covered by oceans. These bodies of water are vast reservoirs of renewable energy. Ocean Thermal Energy Conversion technology, known as OTEC, uses the ocean's natural thermal gradient to generate power. In geographical areas with warm surface water and cold deep water, the temperature difference can be leveraged to drive a steam cycle that turns a turbine and produces power. Warm surface sea water passes through a heat exchanger, vaporizing a low boiling point working fluid to drive a turbine generator, producing electricity. OTEC power plants exploit the difference in temperature between warm surface waters heated by the sun and colder waters found at ocean depths to generate electricity. This process can serve as a base load power generation system that produces a significant amount of renewable, non-polluting power, available 24 hours a day, seven days a week. In this paper investigated the potential of capturing electricity from water thermal energy in Iranian seas (Caspian Sea, Persian Gulf and Oman Sea). According to the investigated parameters of OTEC in case study areas, the most suitable point in Caspian Sea for capturing the heat energy of water is the south part of it which is in the neighborhood of Iran and the most suitable point in the south water of Iran, is the Chahbahar port.

Keywords: thermal energy, OTEC, Caspian Sea, Persian Gulf, Oman Sea

1. Introduction

Since earliest times, the ocean has been a vast resource for travel, food, pearls, minerals, oil, and much more. Some say that the ocean is the last remaining frontier on earth. Much of the deep seafloor, with its many marvels, remains to be probed. And there's the lure of undiscovered shipwrecks and the riches they might contain. However, there is yet another ocean frontier that some think is much more valuable than buried treasure. This is the ocean's energy frontier, one that we are just beginning to understand and put to work. The movements of ocean waves and currents have tremendous energy. And a vast amount of heat energy from the sun is stored in our seas. Both of these ocean energy resources can be put to work generating electricity with today's technology. The ocean can produce two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves.

Oceans cover more than 70% of Earth's surface, making them the world's largest solar collectors. The sun's heat warms the surface water a lot more than the deep ocean water, and this temperature difference creates thermal energy. Just a small portion of the heat trapped in the ocean could power the world. Ocean thermal energy is used for many applications, including electricity generation. There are three types of electricity conversion systems: closed-cycle, open-cycle, and hybrid. Closed-cycle systems use the ocean's warm surface water to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and turns a turbine. The turbine then activates a generator to produce electricity. Open-cycle systems actually boil the seawater by operating at low pressures. This produces steam that passes through a turbine/generator. And hybrid systems combine both closed-cycle and open-cycle systems.

Ocean mechanical energy is quite different from ocean thermal energy. Even though the sun affects all ocean activity, tides are driven primarily by the gravitational pull of the moon, and waves are driven primarily by the winds. As a result, tides and waves are intermittent sources of energy, while ocean thermal energy is fairly constant. Also, unlike thermal energy, the electricity conversion of both tidal and wave energy usually involves mechanical devices.

Two-thirds of the earth's surface is covered by oceans. These bodies of water are vast reservoirs of renewable energy. In a four day period, the planet's oceans absorb an amount of thermal energy from the sun and kinetic energy from the wind equivalent to all the world's known oil reserves. Several technologies exist for harnessing these vast reserves of energy for useful purposes. The most promising are ocean thermal energy conversion (OTEC) and wave power plants. Both of these produce electricity from the oceans' reserves of renewable energy. As the ultimate source of energy from the oceans is the sun, ocean energy systems are renewable, have no fuel costs and are relatively nonpolluting when compared to conventional sources of energy such as coal, oil and natural gas. Unfortunately, the technologies for harnessing the oceans' energy on a large scale are still in the early stages of their development and have high initial costs, making them more expensive than conventional alternatives.

2. Ocean Thermal Energy Conversion

Ocean Thermal Energy Conversion (OTEC) power plants exploit the difference in temperature between warm surface waters heated by the sun and colder waters found at ocean depths to generate electricity. A temperature difference of 20°C or more between surface waters and water at depths of up to 1000 m is required. This situation can be found in tropical and sub-tropical oceans between the latitudes of 25oS to 32oN. The concept of OTEC was first envisioned by Jacques Arsene d'Arsonval, a French physicist, in 1881. The first working OTEC system was built in Cuba in 1930, by Georges Claude, the inventor of the Neon lamp [1]. OTEC power plants can be located either on-shore or at sea, with the generated electricity transmitted to shore by electrical cables, or used on site for the manufacture of electricity intensive products or fuels. For OTEC plants situated on shore to be economical, the floor of the ocean must drop off to great depths very quickly. This is because a large portion of the electricity generated by an OTEC system is used to pump the cold water up from the depths of the ocean. The longer the cold water pipe, the lower the net electrical output of the power plant. OTEC uses the ocean's warm surface water with a temperature of around 25°C (77°F) to vaporize a working fluid, which has a low-boiling point, such as ammonia. The vapor expands and spins a turbine coupled to a generator to produce electricity. The vapor is then cooled by seawater that has been pumped from the deeper ocean layer, where the temperature is about 5°C (41°F). That condenses the working fluid back into a liquid, so it can be reused. This is a continuous electricity generating cycle. The efficiency of the cycle is strongly determined by the temperature differential. The bigger the temperature difference, the higher the efficiency. The technology is therefore viable primarily in equatorial areas where the year-round temperature differential is at least 20 degrees Celsius or 36 degrees Fahrenheit. The distinctive feature of OTEC is the potential to provide baseload electricity, which means day and night (24/7) and year-round. This is a big advantage for for instance tropical islands that typically has a small electricity network, not capable of handling a lot of intermittent power.

3. Ocean Thermal Energy Conversion (OTEC) Systems

A great amount of thermal energy (heat) is stored in the world's oceans. Each day, the oceans absorb enough heat from the sun to equal the thermal energy contained in 250 billion barrels of oil. OTEC systems convert this thermal energy into electricity — often while producing desalinated water. Some energy experts believe that if it could become cost-competitive with conventional power technologies, OTEC could produce billions of watts of electrical power. Bringing costs into line is still a huge challenge, however. All OTEC plants require an expensive, large diameter intake pipe, which is submerged a mile or more into the ocean's depths, to bring very cold water to the surface. This cold seawater is an integral part of each of the three types of OTEC systems: closed-cycle, open-cycle, and hybrid.

Lockheed Martin and Reignwood Group recently signed a contract to design a 10-megawatt OTEC power plant – the world's largest OTEC project developed to date (Figure 1). Lockheed Martin's history with OTEC began in the 1970s, where the heritage Lockheed Martin Ocean Systems Division, based in Sunnyvale, California, developed a mini OTEC plant, which ran for three months and successfully generated 50 kilowatts of electricity [3].

3.1 Closed-Cycle

Closed-cycle systems use fluid with a low-boiling point, such as ammonia, to rotate a turbine to generate electricity. Here's how it works (Figure 2). 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.

3.2 Open-Cycle

Open-cycle OTEC uses the tropical oceans' warm surface water to make electricity (Figure 3). 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, which has left its salt behind in the low-pressure container, is almost pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.

3.3 Hybrid

Hybrid systems combine the features of both the closed-cycle and open-cycle systems (Figure 4). In a hybrid system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, similar to the open-cycle evaporation process. The steam vaporizes a low-boiling-point fluid (in a closed-cycle loop) that drives a turbine to produces electricity.

4. The Best Locations for OTEC Systems

Ocean thermal energy conversion (OTEC) generates electricity indirectly from solar energy by harnessing the temperature deference between the sun-warmed surface of tropical oceans and the colder deep waters. A significant fraction of solar radiation incident on the ocean is retained by seawater in tropical regions, resulting in average year-round surface temperature of about 28°C. Deep, cold water, meanwhile, forms at higher latitudes and descends to flow along the seafloor toward the equator. The warm surface layer, which extends to depths of about 100 – 200 m, is separated from the deep cold water by a thermo-cline. The temperature difference , ΔT , between the surface and thousand – meter depth rang from 10 to 25°C , with large differences occurring in equatorial and tropical waters , as depicted in Figure 5. Δ T establishes the limits of the performance of OTEC power cycles; the rule of thumb is that a differential of about 20°C is necessary to sustain viable operation of an OTEC facility.Since OTEC exploits renewable solar energy; recurring costs to generate electrical power are minimal. However, the fixed or capital costs of OTEC system per kilowatt of generating capacity are very high because large pipelines and heat exchangers are needed to produce relatively modest amounts of electricity. These high fixed costs dominate the economics of OTEC to the extent that it currently cannot compete with conventional power systems, except in limited niche markets. Considerable effort has been expended over the past two decades to develop OTEC by products, such as fresh water, air conditioning, and mariculture that could offset the cost penalty of electricity generation.

4.1 Persian Gulf and Oman Sea

Persian Gulf is situated in south west of Asia continent, between Arab island in south west and Iran from north east. The length of this gulf is 917 kilometer which is between the Hormoz strait to Arvand River in the North West .And its width is variable and these variation is between 47-370 kilometers. The area of the Persian Gulf is about 239000 square kilometer and the deepest point which is measured is 91 meter .This Sea is limited to the north by Iran and to the south by Oman and United Arab Emarities.

The Oman Sea is about 560 kilometer in length and its north depth is about 50 to 200 meter. And this depth is increased by getting near the Arab sea.

The geographical situation of Persian Gulf (altitude and latitude) is between 47.5 and 59 west and between 23.5 and 30.5 degree in north. Thus the humidity and temperature is high and with respect to the low latitude it's completely predictable.

The water temperature of this region because of geographical situation of the Gulf is relatively high and this is gradually increased by going to the south. As it says the Persian gulf and Oman sea are situated in tropical and its surface water temperature is too high. This temperature in the Persian Gulf is about 30 degree and in Oman sea about 32 degree and by this way capturing energy from this heat reservoir is investigated.

4.2 Caspian Sea

The khazar or Caspian Sea is a huge lake in north of Iran. This lake is situated between Iran Turkmenistan Kazakhstan Russia and Azerbaijan. the Caspian sea with an area about 3.5 million square kilometer is situated between 35 till 60 altitude in north and 40 to 60 in east and its estimated length is about 1205 kilometer and its width about 554 kilometer. In water physics of Caspian Sea it could be divided to three sections which is north Caspian middle Caspian and south Caspian these sections in area point of view are a little different. But in depth are very different and thus its physical characteristics are different. the south part of this sea which is laid in Iran border are in fact the most deepest and point of the sea and full of water the deepest point is 1100 meter and the mean depth is estimated to be about 350 meter .the temperature is the same as other physical characteristics in the length of the sea is very different. The temperature in north part of the sea is very low which in the winter it freeze and this temperature is gradually increase by getting to the south and in result the south coast is the warmest point of this sea.

The temperature difference in column of water in the Caspian Sea is clear .in addition the thermo-cline phenomena in south Caspian and especially in the summer is distinguished. The higher difference in temperature takes place at low depth and in summer (in about 200 meter) this difference in temperature is rare one in this depth in all over the world. Figure (7) shows the temperature in the south part of the sea. Thus the south region of the sea which is in Iran side is the most suitable points for capturing the heat energy.

4.3 Benefits and Drawbacks of OTEC Systems

Unlike electrical generation from most other forms of renewable energy which varies with weather and time of day, such as solar and wind energy, OTEC power plants can produce electricity 24 hours per day, 365 days per year. This capability makes OTEC an attractive alternative to conventional base load power plants powered by fossil fuels or nuclear fission. Fresh water production is just one of the potential beneficial by-products of OTEC. The cold deep ocean water can be used for aqua-culture (fish farming) as it is pathogen free and nutrient rich, or air-conditioning and refrigeration in nearby buildings. OTEC power plants have some negative impacts on the natural environment, but overall they are a relatively clean, non-polluting source of electricity when compared to conventional options such as fossil fuels or nuclear power. Cold water released at the ocean's surface will release trapped carbon dioxide, a greenhouse gas, but emissions are only about 4-7% of those from a fossil fuel power plant. Discharging the cold water at the oceans' surface could change local concentrations of nutrients and dissolved gases. However, this could be minimized by discharging the cold water at depths of greater than 50 m.

At the present time, despite the fact that OTEC systems have no fuel costs and can produce useful by-products, the high initial cost of building such power plants makes OTEC generated electricity more expensive than conventional alternatives. As such, OTEC systems at the present time are restricted to experimental and demonstration units. Island nations which currently rely on expensive, imported fossil fuels for electrical generation are the most promising market for OTEC. More experience in building OTEC power plants and standardized plant designs could bring OTEC costs down in the future. Heightened world concern over environmental issues such as global warming could also hasten the development of OTEC as a practical source of electricity.

Synergetic products (Figure 8):

1. The first by-product is fresh water. A small hybrid 1 MW OTEC is capable of producing some 4,500 cubic meters of fresh water per day, enough to supply a population of 20,000 with fresh water. OTEC-produced fresh water compares very favourably with standard desalination plants, in terms of both quality and production costs.
2. A further by-product is nutrient rich cold water from the deep ocean. The cold “waste” water from the OTEC is utilised in two ways. Primarily the cold water is discharged into large contained ponds, near shore or on land, where the water can be used for multi-species mariculture producing harvest yields which far surpass naturally occurring cold water upwelling zones, just like agriculture on land.
3. The cold water is also available as chilled water for cooling greenhouses, such as the Seawater Greenhouse or for cold bed agriculture. The cold water can also be used for air conditioning systems or more importantly for refrigeration systems, most likely linked with creating cold storage facilities for preserving food. When the cold water has been used it is released to the deep ocean.

5. Conclusion

The capturing of heat energy based on two parameters; depth and heat deference between surface water and deep water, so;

a) The most suitable point in Caspian Sea for capturing the heat energy of water is the south part of it which is in the neighborhood of Iran, because:

a-1) the most suitable points for capturing heat energy is depth waters, and the south part of Caspian Sea, which is in the neighborhood of Iran, is the deepest part of it,

a-2) Measurement shows that in the south part of Caspian Sea the temperature difference between the surface and depth is relatively higher than the other parts of it.

b) The most suitable point In the south water of Iran, is the Chahbahar port, because:

b-1) Chahbahar port has notably depth water in comparison to other points in the south water of Iran.

b-2) Measurement shows that in this region amount of absorbing the heat energy is

higher than the others because of the neighborhood to the tropics.

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Appendix

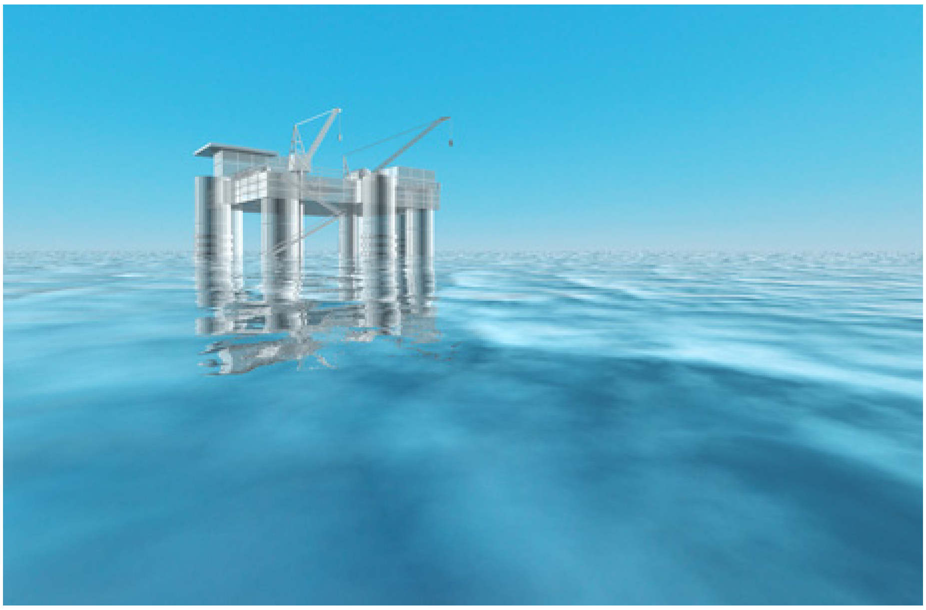

Figure 1. Lockheed Martin and Reignwood Group recently signed a contract to design a 10-megawatt OTEC power plant – the world's largest OTEC project developed to date

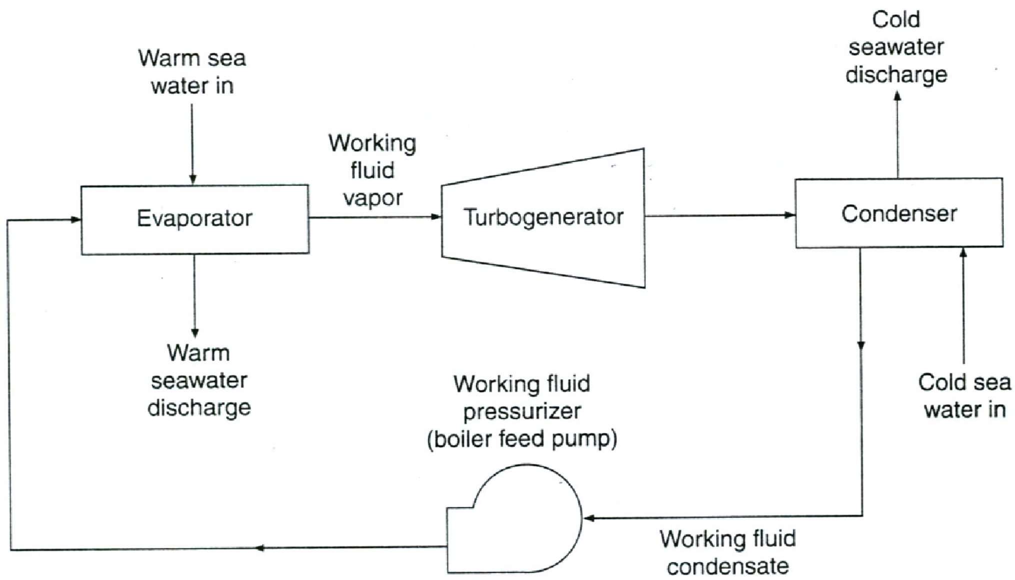

Figure 2. Schematic diagram of a closed-cycle OTEC system

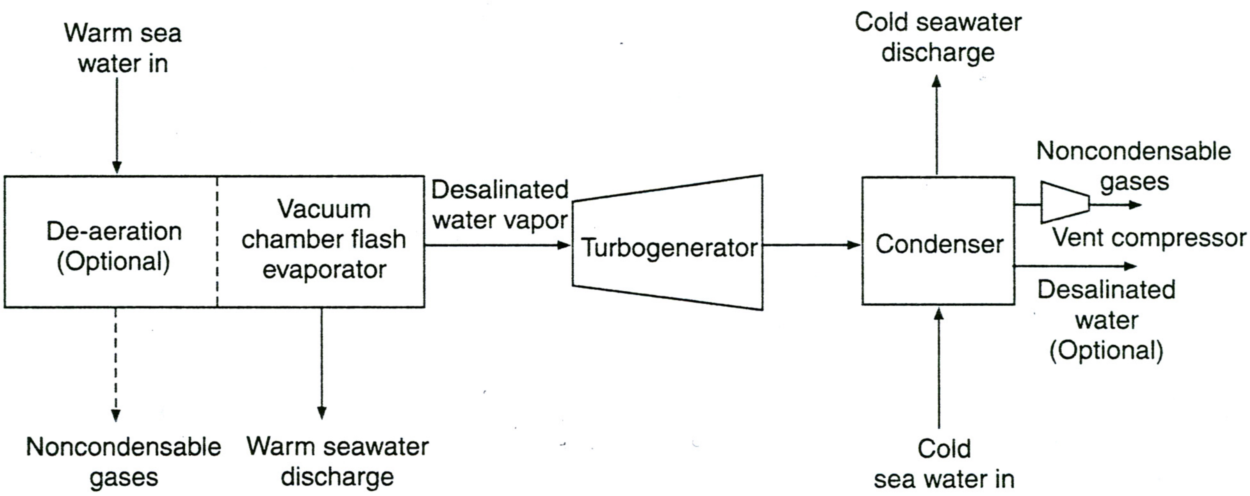

Figure 3. Schematic diagram of an open-cycle OTEC system

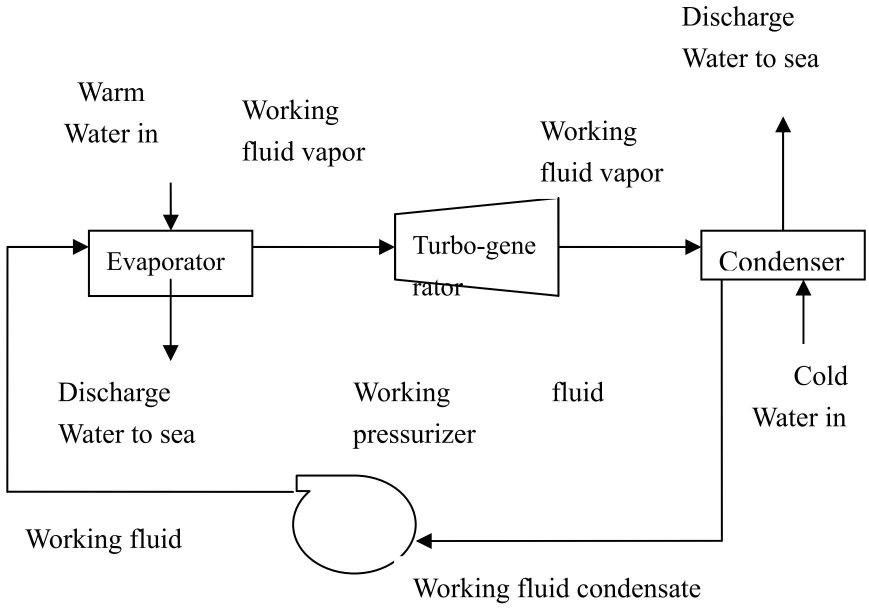

Figure 4. Schematic diagram of a Hybrid OTEC system

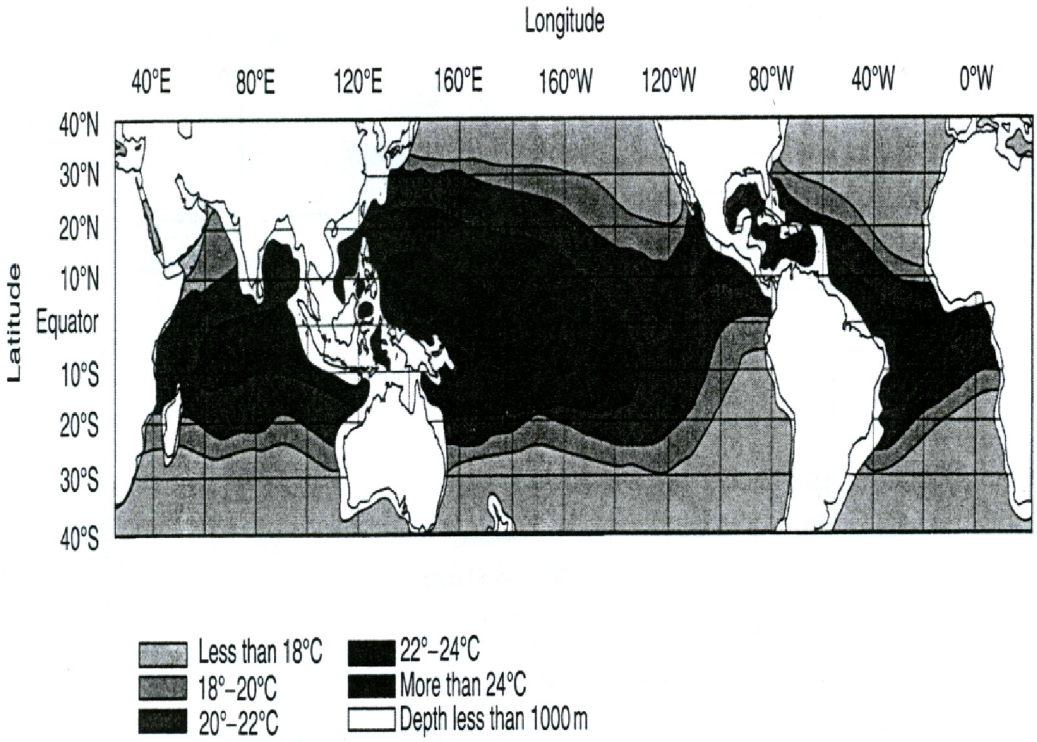

Figure 5. Temperature difference between surface and deep sea water in regions of the world; the darkest areas have the greatest temperature difference and are the best locations for OTEC system

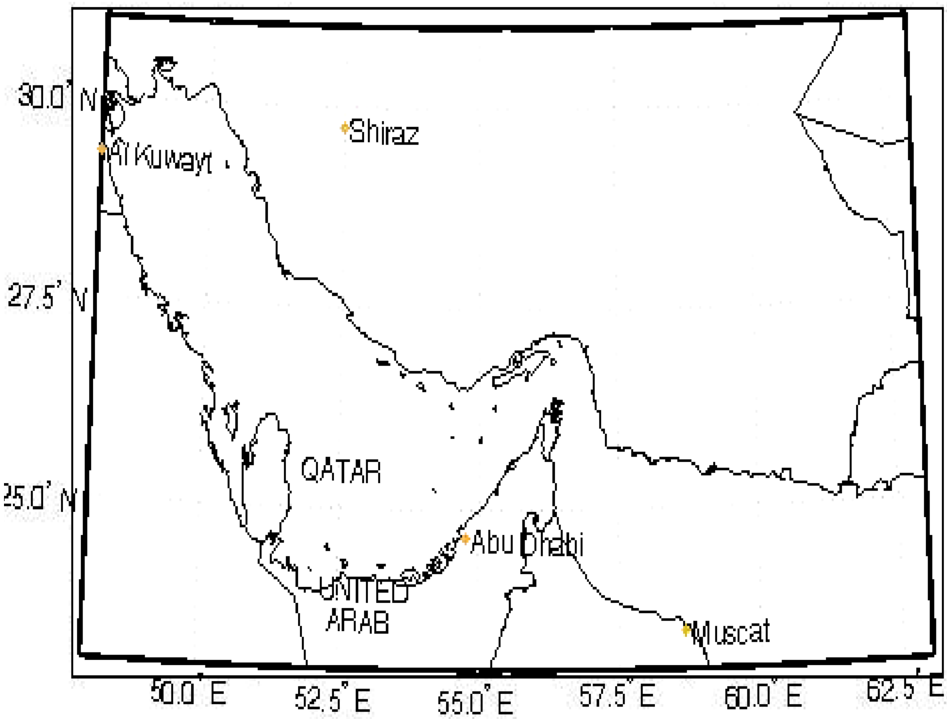

Figure 6. Persian Gulf & Oman Sea

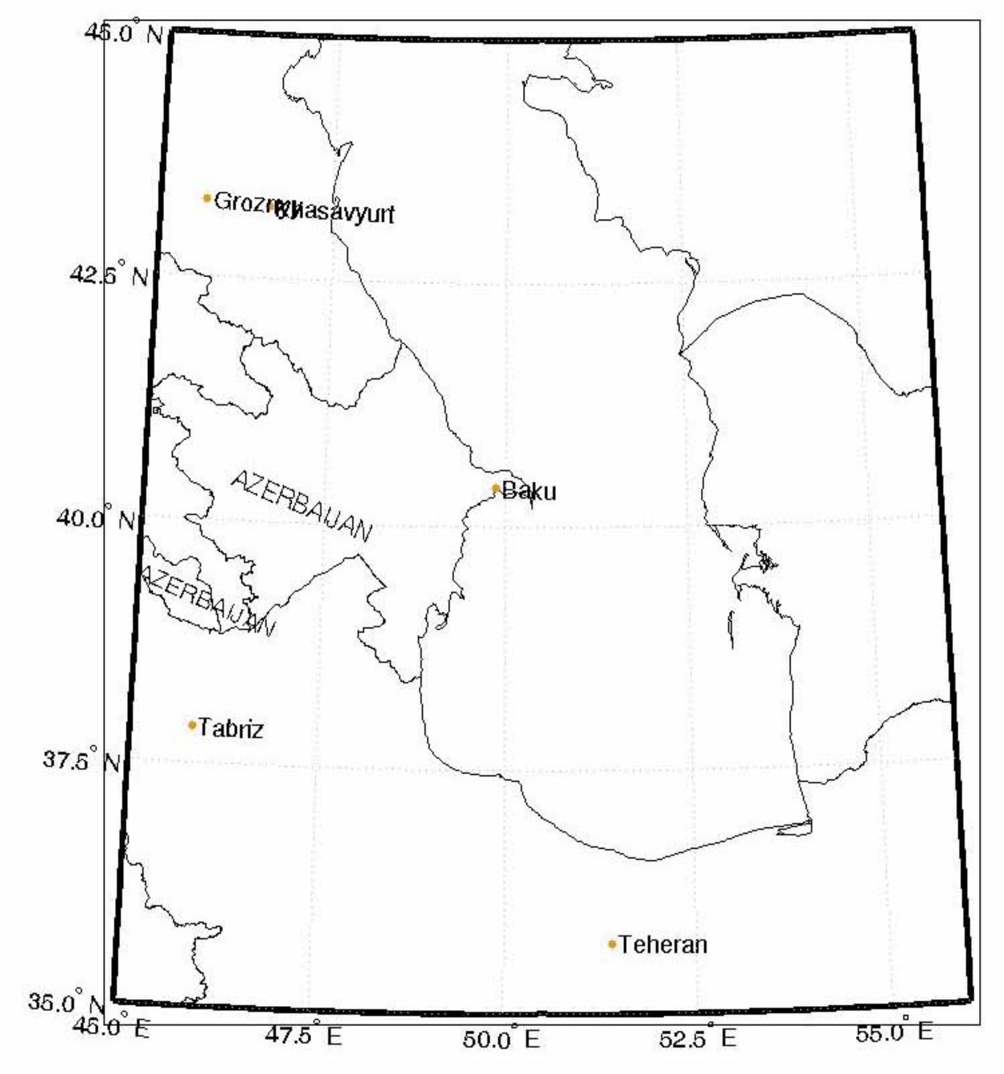

Figure 7. Caspian Sea

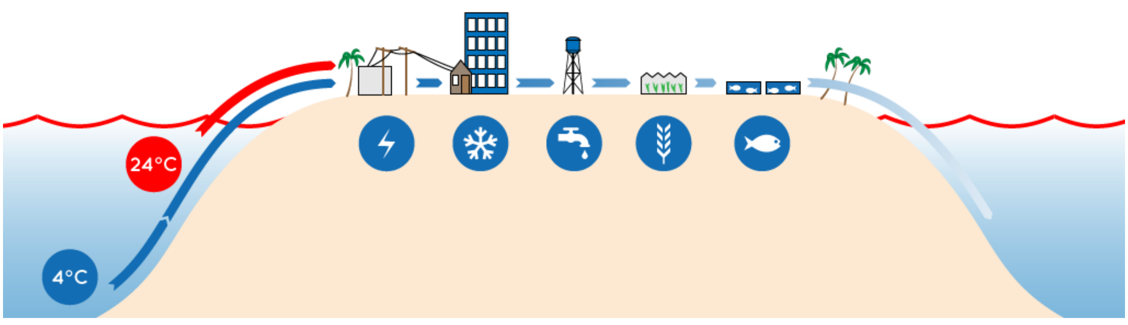

Figure 8. Cold water applications