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Review

Sustainable water and energy in Gaza Strip

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Abstract

Shortage of fresh water is a common problem in different areas of the world including the Middle East. Desalination of seawater and brackish water is the cheapest way to obtain fresh water in many regions. This research focuses on the situation in Gaza Strip where there is a severe shortage in the energy and water supply. The depletion of fresh water supplies and lack of wastewater treatments result in environmental problems. A solar-powered co-generation plant producing water and energy is proposed to be a suitable solution for Gaza Strip. Solar energy, using concentrating solar thermal power (CSP) technologies, is used to produce electricity by a steam cycle power plant. Then the steam is directed to a desalination plant where it is used to heat the seawater to obtain freshwater.

The main objective of this research is to outline a solution for the water problems in Gaza Strip, which includes a co-generation (power and water) solar-powered plant. The research includes four specific objectives: (1) an environmental and economic comparison between solar and fossil fuel energies, (2) technical details for the co-generation plant, (3) cost and funding, (4) the benefits.

Keywords: Solar energy; Cost comparison; Desalination; Co-generation plan; Concentrating solar thermal power technologies; Brine disposal

Contents

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1. Introduction

Gaza Strip is 360 km^2 with a high-density population of about 3823 persons/km^2 [1] (most of the people in Gaza Strip are the generations of the refugees who fled their homes in the 1948 and 1967 Arab–Israeli wars [2]), so Gaza Strip represents one of the most densely populated areas.

There is now a water crisis in Gaza Strip. According to one estimate, the people of Gaza over-pump approximately 160 million cubic meters (MCM) of water from the coastal aquifer per year, but the sustainable yield of the Gaza sub-aquifer is about 100 MCM/year [2] (sustainable yield is the amount of water that can be extracted from the aquifer annually, while still maintaining ground water levels and chemical composition [3]).

Because of the depletion of water and the declining economic situation, Gaza Strip is suffering from environmental problems such as salination of fresh water, contamination of underground water resources (most wells in Gaza Strip produce nonpotable water by the standards of World Health Organization [2]), lack of adequate sewage treatment, desertification, soil degradation and depletion [1], and water-borne diseases. Besides salts, which cause kidney disease, nitrates from solid waste and fertilizers are the most common water contaminants. The nitrates cause blue baby syndrome [2], a fatal condition in which the hemoglobin (Fe^{2+}) in an infant's red blood cells is oxidized to methemoglobin (Fe^{3+}), which is unable to deliver oxygen. The lack of oxygen in the blood will result in a bluish discoloration of the skin and mucous membranes [4].

In spite of the fact that these problems are caused by the depletion of water, it is worthwhile to mention that people in Gaza Strip consume 70 liters per capita per day (this includes the public use as hospitals, schools, business, and public institutions), while the World Health Organization and the United States Agency for International Development agreed that the minimum consumption per capita per day is 100 liters for public health and hygiene [2].

As the population in Gaza Strip increases (population growth rate is 3.77%/year [1]), the consumption of water and energy will increase and the deficit in water supply and energy resources will increase, leading to a severe economical crisis that will result in a significant rise in the probability of an outbreak of warfare.

2. Optimum solution

Water problems are not local; they extend into the neighboring regions. For example, in the Gaza Strip, aquifer is readily deteriorating due to its fast depletion, and this will have serious impacts on the coastal plain aquifer within Israel itself. This is due to the strong probability that there exists an interchange between the two [5]. If long-term needs of Gaza Strip are to be taken into account, sustainable resources of both water and energy should be secured. We will demonstrate an optimum solution for the water and energy crisis in Gaza Strip, and that is a co-generation plant producing both water and energy. It is clear that the only source of water left for Gaza Strip is seawater desalination; so building a desalination plant is an urgent necessity to save the area from a water disaster. The initial costs of building a co-generation plant will be more costly than a desalination plant only, but since water and electricity are both generated from such plants, over time it will be very cost effective. In addition, the co-generation plant will supply Gaza Strip with electricity and reduce its dependence on electricity imported from Israel.

The co-generation plant can be powered by fossil fuels or by solar energy, but a comprehensive comparison between fossil fuels and solar energy (taking into consideration long-term economical and environmental impacts) favors solar energy [6].

3. Solar energy versus fossil fuel

3.1. Environmental

Fossil fuels are nonrenewable sources of energy, they have adverse impacts on the environment, and their supply is finite. Burning fossil fuels is the largest single source of pollution in the atmosphere. The combustion of fossil fuels produces air pollutants including sulfur dioxide, nitrogen oxides, hydrocarbon compounds, carbon monoxide and particulate matter. In the atmosphere, sulfur dioxide and nitrogen oxides are converted into sulfuric acid and nitric acid, the components of acid rain. Nitrogen oxides and volatile hydrocarbons react in sunlight to form ground-level ozone, the principal component of urban smog [7]. Burning of fossil fuels is a major factor that contributes to the global climate change, which is resulting from the build-up of greenhouse gases (gases that trap heat in the atmosphere). Global climate change has created global concern for the entire world, since it exacerbates the floods, droughts, storms, diseases, and famines.

For all these reasons, using renewable energy has become a global trend. In 1997, the Kyoto Protocol was agreed upon; it is the world's only international agreement with binding targets to reduce greenhouse gas emissions. As such, it is the primary tool with which governments of the world can address climate change; so far, 129 countries have ratified or acceded to the protocol [8].

In the Middle East, the combustion of fossil fuel has become a significant problem as the majority of its cities bear the burden of unacceptable levels of air pollution. Cairo, Amman, Jerusalem, Tel-Aviv, and Gaza City all experience pollution levels that, by international standards, are known to threaten public health.

On the other hand, solar energy is a renewable resource; it is abundant, inexhaustible, and free. Solar power has little adverse environmental impact, with none of the polluting emissions or safety concerns associated with conventional energy generation technologies.

There is hardly any pollution in the form of exhaust fumes or even noise during operation. Each square meter of the reflector surface in a solar field is enough to prevent the production of 150–250 kg/year of the greenhouse gas, carbon dioxide. Therefore, solar power can make a substantial contribution towards international commitments to reduce the steady increase in the level of greenhouse gases and their contribution to climate change [8].

Notwithstanding, it is worthwhile to mention that solar energy is intermittent. There is no radiation at night, and in winter and cloudy days the solar radiation intensity is low. This problem can be solved by supporting solar energy with fuel heaters or using storage heat medium.

3.2. Economy

Fossil fuel costs are expected to rise with growing scarcity. The fact that Gaza Strip is poor in fossil fuel and relies on imported supplies already places a heavy financial burden on the people. In addition, the supply of fossil fuels to the region is highly affected by the political events in the Middle East; therefore there is no guarantee of steady supply and/or stable prices.

In the beginning, fossil-powered plants may be more cost effective than solar-powered plants; but in the long run solar power plants will be economically superior. This has been demonstrated by two separate studies.

The first study is a joint effort by Greenpeace, the European Solar Thermal Power Industry Association (ESTIA), and the International Energy Agency's (IEA) Solar PACES Programme [8]. This study, entitled ''Concentrated Solar Thermal Power—Now'', demonstrates that there are no technical, economic or resource barriers to supply 5% of the world's electricity needs from solar thermal power by 2040 taking into account a projected doubling in global electricity demand. This study illustrates the different technologies used in solar thermal power, their costs, and benefits; and expects that electricity cost will drop to 7–8 € cents/kWh in the medium term and to 5 € cents/kWh in the long term. This study predicts that cost of solar electricity will reduce to a level competitive with conventional fossil-fueled peak and mid-load power stations within the next 10 years.

The second study is a paper presented at the MENAREC conference in Sana'a, 21–22 April 2004, by Trans-Mediterranean Renewable Energy Cooperation (TREC) [9]. Solar thermal energy for the generation of superheated steam is still slightly more expensive than heat from oil or gas. However, this study shows that technology improvements and economies of scale for large amounts of concentrating solar collectors will make solar energy cheaper than oil or gas in less than 10 years from now. This is dependant on the plant having a capacity of ca. 500 million m^3/year of desalinated water and electricity is produced in co-generation with the desalinated water. (The study assumes an excellent solar location with 2750 kWh/m^2/year irradiation.) This study expects that the solar electricity co-generated with the desalinated water to be as cheap as 2–5 cents/kWh.

Figs. 1 and 2 compare solar and fossil costs under favorable financial conditions. It is clear that the cost of power and water from solar energy will decrease and become substantially cheaper than from fossil in less than 20 years, while the cost of power and water from fossil fuel will increase [9].

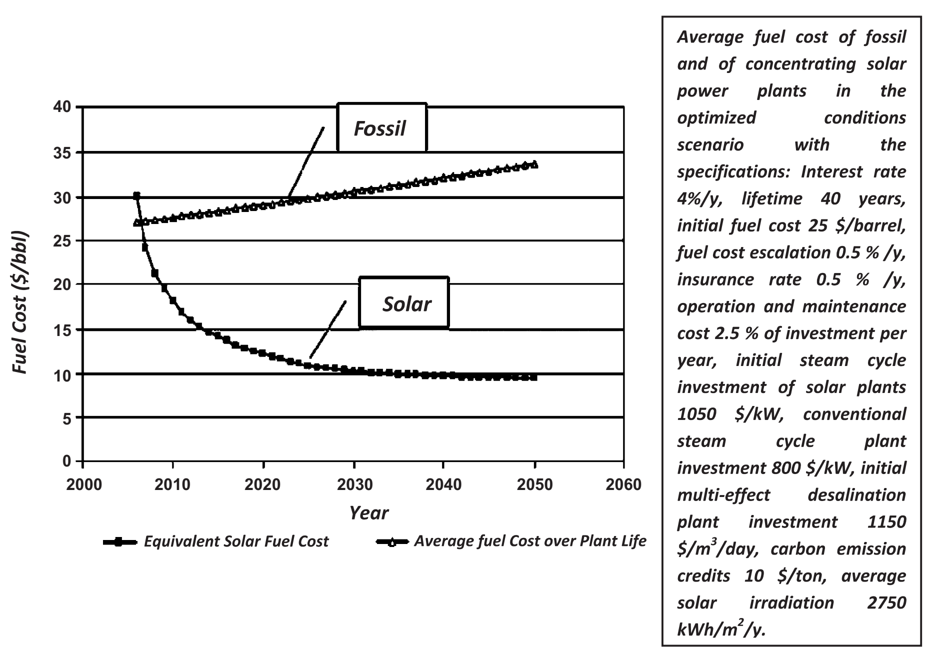

Fig. 1. Average fuel cost of fossil and of concentrating solar power plants [9].

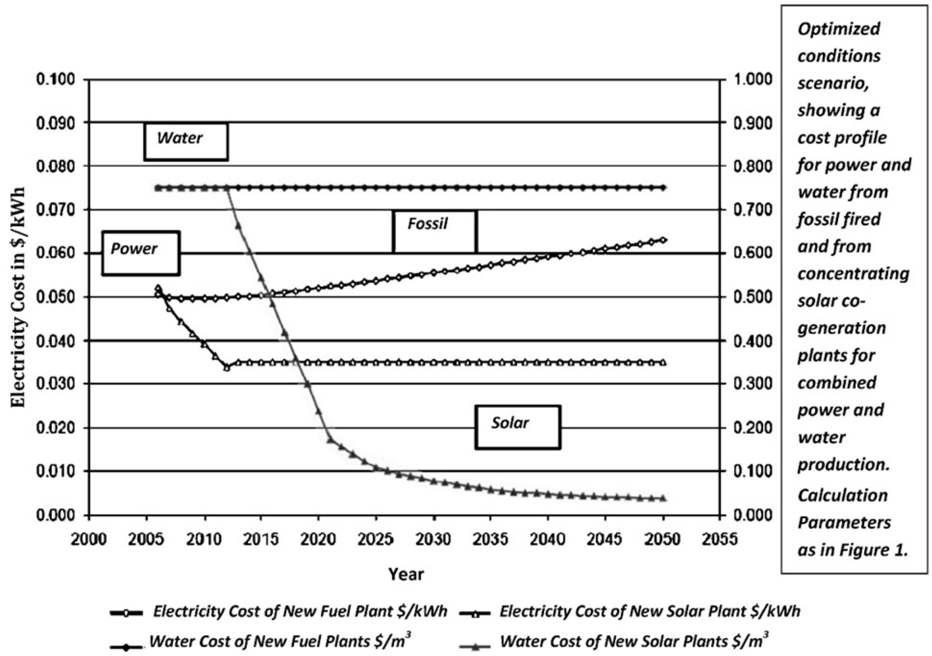

Fig. 2. A cost profile for power and water from fossil fired and from concentrating solar co-generation plants [9].

Figs. 1 and 2 illustrate a scenario with optimized conditions that would lower the costs of the solar energy, where an excellent solar location with 2750 kWh/m^2/year irradiation is combined with a low investment interest rate. Seventy five percent of the investment is covered by a soft loan with 0% interest rate, and 25% by private capital with 16% interest (the same financial conditions are applied to fossil fuel).

The comparison of solar and fossil fuel costs in Fig. 1 shows that solar energy will be cheaper than fossil fuel after only 1 year. Fig. 2 shows that desalinated water could cost <0.20 \$/m^3 after 15 years, and <0.10 \$/m^3 after about 25 years. These low prices of desalinated water will make it also convenient for irrigation.

It is worthwhile to mention that Figs. 1 and 2 are based on an initial fuel cost of 25 \$/barrel with fuel cost escalation of 0.5% yearly, while the prices of oil nowadays are fluctuating between 60 and 70 \$/barrel, giving solar energy an even greater advantage over fossil fuel.

Solar technology can guarantee long-term and large-scale production of low cost power and water in a sustainable and environmentally friendly way. It is an investment into continued cost reduction. So, it is concluded from both studies that solar-powered plants are preferable not only because they are friendlier to the environment, but also because they are more cost effective in the long term [8,9].

4. Co-generation (energy and water) plant

The proposed co-generation plant has a water capacity of 100 MCM/year and a power capacity of 2.5 billion kWh/year. This plant will be built in three stages. The power and water capacities that will be reached in each stage and the expected time are illustrated in Table 1. The total area needed for the project is approximately 13 km^2, since 5 km^2 is required for the collector field to produce 1 TWh/year of electricity [9,10].

Table 1
Power and water capacities and the expected time for the project stages

Stage	Power capacity (million kWh/year)	Water capacity (MCM/year)	Expected time (year)
1	625	25	3–5
2	1250	50	3–5
3	2500	100	4–8

The eastern border of the Gaza Strip is a suitable location for this project (Fig. 3 [11]). This location is preferred because Gaza Strip is densely populated, so the plant cannot be put inside the Gaza Strip. Besides that, the Gaza Strip is a very narrow area which makes the location of the plant not far from the shore, which should be dedicated to fishing and tourism. In addition, this location permits expansion of the plant, in the future, to cover all needs of the Gaza Strip and export water and power to West Bank and Najav Desert (Fig. 3). The expansion of the project requires collaboration between the Palestinian authority and Israel, where more area of the eastern arid land (Najav Desert) is needed for the project. Also the pipelines and the grid need to pass through the Najav Desert for export purposes.

5. Technical details

Solar thermal co-generation plant consists of three major parts (subsystems): the solar field, the power

Fig. 3. A suitable location for the co-generation plant, adapted from Ref. [11].

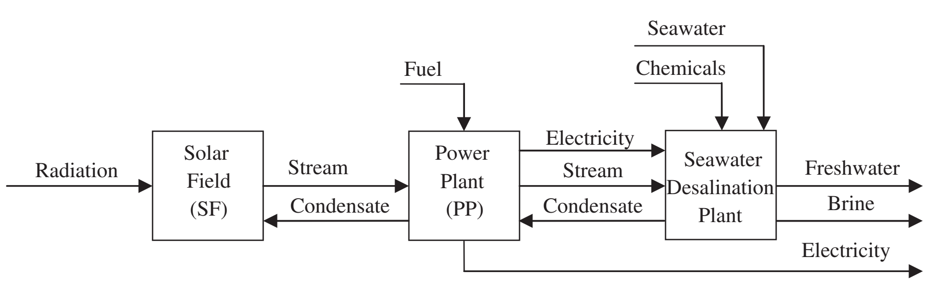

Fig. 4. Schematic flow chart of the solar thermal co-generation process [12].

plant, and the seawater desalination plant. Fig. 4 shows schematic chart for the solar thermal co-generation process and the interactions between the three major parts [12].

5.1. The solar field

The solar field consists of concentrating solar thermal power (CSP) technologies. In the CSP technologies,

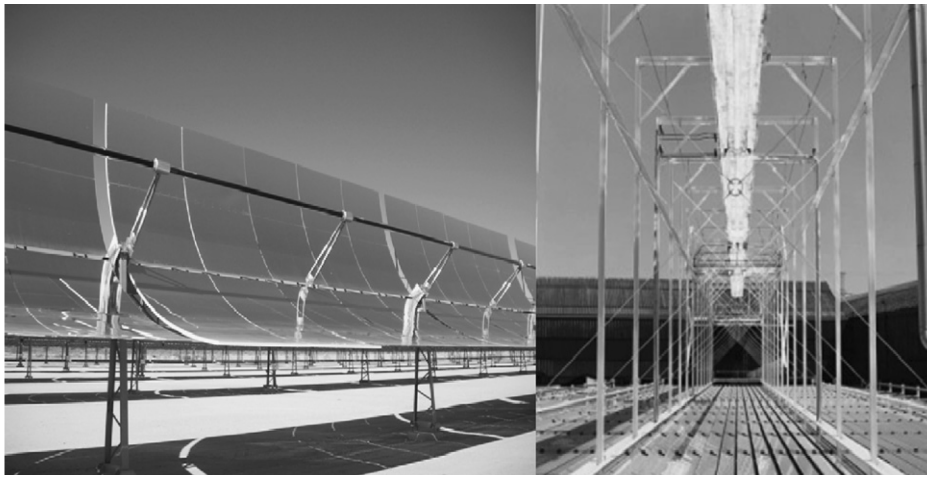

Fig. 5. Parabolic trough (CSP) technology (left), adapted from Ref. [13] and the Fresnel reflector (CSP) technology (right) [14].

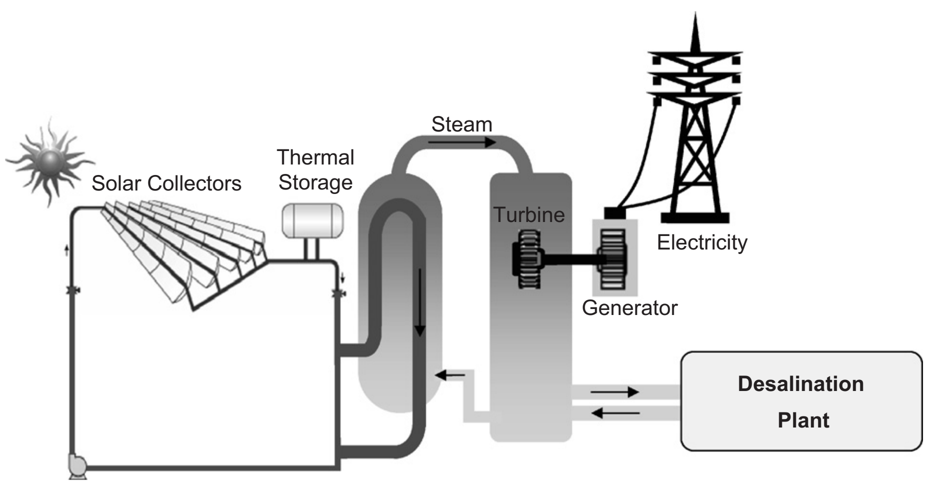

Fig. 6. Simple diagram of the co-generation plant powered by solar field, adapted from Refs. [17,18].

solar radiation is collected and concentrated by mirrors into a receiver where a fluid flowing through the receiver absorbs the heat. This will provide a high temperature medium [8].

Parabolic trough (Fig. 5 [13,14]) is the preferred CSP technology to be used in the first stage. This technology has been demonstrated and already used in the field (California plants [8]).

For the second and third stages, Fresnel technology (Fig. 5) may be used. This technology is new and has a promising future. Fresnel collector plant now is under construction at Liddell power station in Australia. The land area needed for this technology is half the area needed for trough arrays. Besides that, the Fresnel technology is regarded as a lower cost alternative to trough technology [8,14]].

Solar heat collected during the day can be stored in a liquid or solid media for use at night. The storage medium could be molten salts in thermodynamic tanks 250–370 °C (USA), solid ceramics storage (DLR, Germany), mineral oil < 310 °C in Thermo-cline Tank (USA), and concrete [8,14].

In this project molten salts can be used as a storage medium. Molten salts provide an efficient, low-cost storage medium with a simple system design. In addition, molten salts are non-flammable and nontoxic [15].

There are two possibilities of storage for molten salts. The first is direct storage using the heat transfer fluid (HTF) as the sensible storage media. Other possibility is the transfer of thermal energy from the HTF to some type of storage media [16].

5.2. The power plant

A steam cycle power plant, producing the electricity by generators, is combined with the direct steam of the solar field (Fig. 6 [17,18]).

To have a constant full load operation, fuel heaters are used. A fuel-fired steam generator in parallel to the solar field is used to produce the amount of required steam

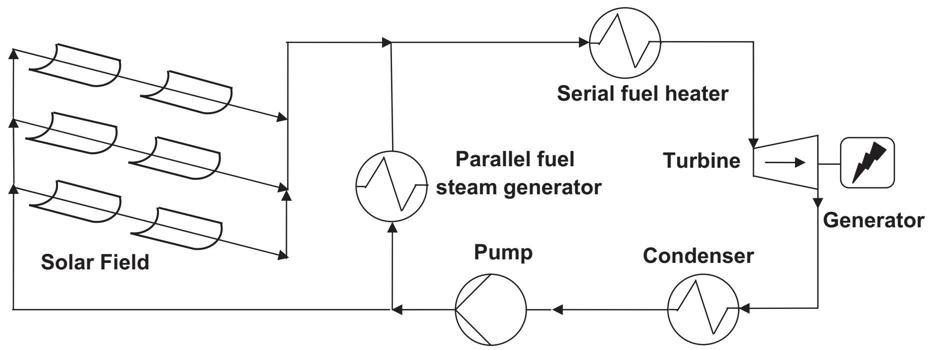

Fig. 7. The solar–thermal hybrid power process, adapted from Ref. [12].

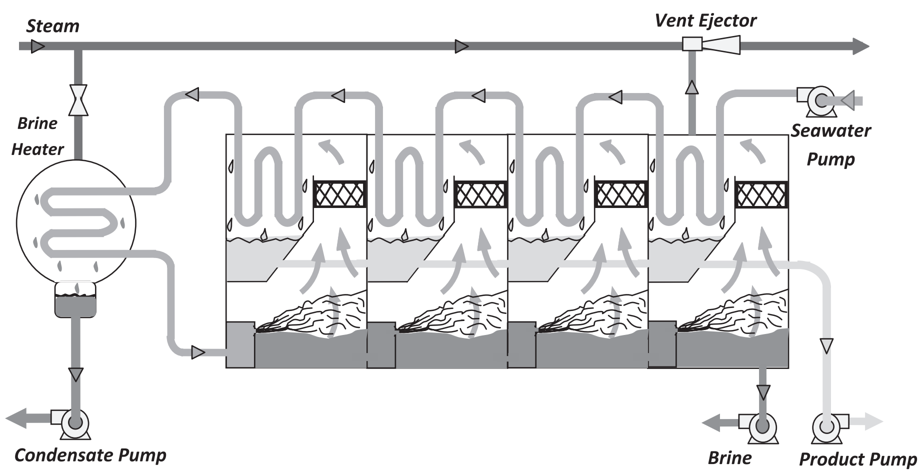

Fig. 8. The principle of the multi-stage flash distillation (MSF), adapted from Ref. [21].

(420–510 °C) in cloudy days. Moreover a fuel-fired serial heater is used to heat the steam to the required temperature in low intensity solar radiation days (Fig. 7). These fuel heaters are hopefully to be replaced by expansion of the solar field and more developed thermal storage [14].

5.3. Seawater desalination plant

There are two different commercial desalination methods:

- Membrane processes, such as reverse osmosis.
- Thermal processes (phase-change processes), such as multi-stage flash (MSF) and multi-effect evaporation (MEE) or multi-effect boiling (MEB) [19].

Reverse osmosis is the process of pushing a solution (seawater) through a membrane (semipermeable polymer layer of microscopic thickness) that traps the solute (salts) on one side and allows the pure solvent (fresh water) to be obtained from the other side, by applying a pressure in excess of the osmotic pressure.

The membranes used for reverse osmosis have no pores, and it is designed to only allow water to pass through it by diffusion. This process requires a high pressure to be exerted on the high concentration side of the membrane, usually 5–20 MPa (50–200 bar) [20].

Thermal process is the separation of the salt and fresh water by evaporating the water out of the solution and collecting the distillate using heat energy [14]. The main thermal process used for large-scale desalination plants is MSF. This process involves the heating of seawater in a container known as a brine heater (Fig. 8 [21]). The heated water is passed to another container known as a "stage", where the surrounding pressure is lower than that in the brine heater.

The sudden introduction of the heated water into a lower pressure "stage" causes it to boil so rapidly as to flash into steam. Only a small percentage of this water is converted into steam. Consequently, the remaining water will be sent through a series of additional stages, each possessing a lower ambient pressure than the previous "stage". As vapor steam is generated, it is condensed on tubes of heat exchangers that run through each stage and carrying the seawater to the brine heater [22].

Another thermal process used in (small-scale) desalination plants is MEE. This process is similar to MSF in using the steam as a heat source to evaporate the salty water in a cascade, but in MEE process the condensation of the vapor of the previous stage is used to evaporate water out of the boiling brine at lower pressure, and liquid at the boiling point is continuously supplied with heat from an external source (e.g. a heated metal tube) at lower pressure [14].

Thermal process is the preferred technology for this project, since according to a diploma thesis, "Case Study of a Concentrating Solar Power Plant for the Co-generation of Water and Electricity" [12], both technologies (thermal and membrane processes) are close up, regarding the economical comparison (Fig. 9), with a 5–10% lower water cost at all sites for the thermal process. This study made the comparison (for small scale plants below 5000 m^3/day) between the solar thermal co-generation process with reverse osmosis and the solar thermal with MEE [12].

Moreover, recalling that the average salinity of Mediterranean Sea is approximately 35.5 g of dissolved salts/kg seawater [23] the case study diploma [12] has shown the influence of the seawater salinity on the water costs of the co-generation process (Fig. 10). This study favors the MEE for water salinity higher than 31 g/kg.

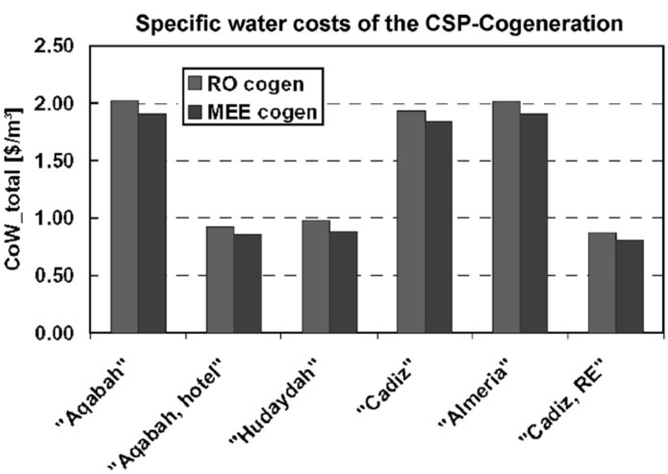

Fig. 9. Specific water costs CoW total of a CSP co-generation plant with the two desalination technologies at 7% interest rate [12].

The suitable thermal technology for this project is multi-stage flash (MSF) since it is widely used for large-scale plants.

6. Concentrate (brine) disposal

There are different options for the disposal of the concentrate rejects: disposal to a wastewater plant, deep-well injection, co-locating with an existing power or wastewater treatment plant, and submarine ocean outfalls.

Disposal to wastewater plant: In this method, the concentrate is discharged to the sewer system; but precautions should be taken to insure that the wastewater treatment plant can still meet water quality standards after the addition of the reject concentrate. This may require pretreatment of the concentrate.

Deep-well injection: This method uses wells to inject waste fluid at least 0.4 km below the lowest underground drinking water source. The physical properties of the rock formation must enable it to contain the injection fluid and prevent contamination of overlying drinking water aquifers.

Co-locating with an existing power or wastewater treatment plant where seawater desalination plant can be co-located with an existing power plant to dilute the reject stream with the power plant cooling water discharge. This project is already a co-generation plant producing electricity and water, so the brine will be mixed with the cooling water to be discharged together.

Submarine ocean outfalls: Submarine ocean outfalls are submerged offshore pipes that discharge the concentrate directly to sea. There are two types of ocean outfalls. First is the single port outfall, which is a submerged pipe with a single efflux. This type is applied in situation where there is a very large bulk-mixing ratio. The second type is multi-port diffuser, consists of header pipe containing two or more ports. These ports inject a series of turbulent jets at high velocity into the sea. Multi-port diffusers are used

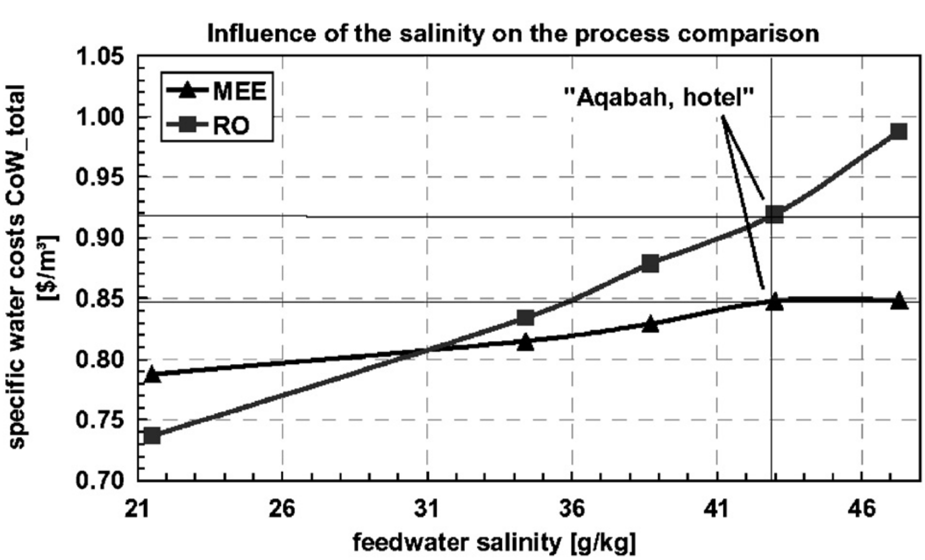

Fig. 10. The corresponding power and freshwater outputs at the optimum desalination configuration depending on the seawater salinity [12].

where maximizing dispersion is imperative, under water slope stability is good, and effluent flow rates are greater than 1 million gallon per day (mgd) [24].

For this project it is proposed to use part of the brine for salts industry, where the magnitude of this part depends on the market needs. The rest of the brine is to be discharged using submarine ocean outfalls since the plant is not far from the sea.

Further studies are needed to decide which type of ocean outfalls is suitable for the location of disposal in the Mediterranean Sea.

7. The cost

The cost of the project includes the system used such as: parabolic trough, steam turbine, electricity generators, multi-stage desalination and infrastructure (roads, pipe lines, power transmission, etc.). Besides that there are the operation and maintenance costs.

Estimation for the total cost of a plant with capacities of 100 MCM/year for water and 2.5 billion kWh/year for the power is approximately 1.1–1.3 billion US$. This estimation depended on a paper, presented at the MENAREC conference in Sana'a, 21–22 April 2004, by Trans-Mediterranean Renewable Energy Cooperation (TREC) [9] and a paper presented to Forum 2000 in Paraguе (9–10 October 2005) [10].

This cost estimation is high, but more detailed studies for the cost, taking into account that labor in Gaza Strip is cheaper than other places, would result in a lower estimation. The details of the cost need expert engineers who have knowledge of all the technical details of the project and the actual conditions on the ground in Gaza Strip.

Funding this project needs cooperation of different partners from Middle East, Europe, USA, World Bank, Islamic Development Bank and other interested agencies or institutions. As it is mentioned before, the water problem in Gaza Strip is an urgent problem that needs to be solved in order to avoid adverse consequences in the area. Although solving the problem of water in Gaza Strip is an urgent humanitarian need and it should not be part of the regional politics, the project could be one of the benefits Palestinians will gain as being part of the peace process. This project is assumed to be funded by the countries concerned in the peace process and to be managed by Palestinians and an international committee. An inexpensive source of clean water and power will make the other problems in the area less urgent. Jobs, water, and power will raise the quality of life and health, leading to decreased tension in the area.

8. Conclusions

Solving the problem of water in Gaza Strip is an urgent humanitarian need and it should not be part of the regional politics.

The co-generation plant powered by solar energy seems to be an ideal solution for solving Gaza Strip problems. Abundance fresh water can combat desertification and trigger the economic development of arid regions. Besides that expansion of the plant to higher capacities in the future so that water and energy can be exported to the neighbors will bring economical benefits to the region and enhance the opportunities of peace. In addition, exporting to West Bank will solve the water and energy problems they are facing. This also will help in creating an independent and integrated Palestinian economy and will enhance the opportunities of peace since the economical factor is very crucial in the peace process where most of the conflicts' motive is economical (i.e. controlling energy and water resources). Peace will support the cooperation between the people of the region to fulfill economic development potential and to solve the environmental problems of the region, especially if they have equal opportunities of good life.

More specific technical details and accurate estimation for the cost of this project need to be specified by the experts in this field.

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