

Review on Solar Thermal Desalination in Libya

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Abstract: Libya is suffering from freshwater shortage as most of its land is semi-arid to arid with very low precipitation rates and too limited fresh water sources. Libya is in one of the driest regions of the world with an annual rainfall ranging from just 10 mm to 500 mm, and only 5% of its land receives more than 100 mm annually. This review summarizes the most important published studies related to solar thermal desalination research in Libya. Brief description of the most thermal desalination technologies is also presented. The study has shown that only few in-completed pilot projects were carried-out for desalination using renewable energy. The research activities in the field of using renewable energy especially solar thermal energy to desalinate water are limited and do not give a comprehensive idea on the potential of different thermally driven solar desalination technologies. However, most of the recent pilot studies refer to using CSP desalination in providing most of the future water demand in Libya by 2035. A lot of efforts need to be done to carry-on a genuine research to put strategic plan to tackle the deficit water issue in Libya through using desalination driven by conventional and renewable energies.

ورقة مراجعة عن التحلية الشمسية الحرارية في ليبيا

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ملخص: ليبيا تعاني من مشكلة نقص المياه العذبة نتيجة أن معظم أراضيها صحراوية أو شبه صحراوية بمعدلات سقوط أمطار قليلة جدا ومصادر المياه محدودة جدا. ليبيا إحدى المناطق الجافة مع معدل سنوي لسقوط الأمطار يتراوح بين 10 إلى 500 ملم وان

حوالي 5% فقط من أراضيها يستقبل أكثر من 100 ملم سنويا. هذه الورقة تتناول أهم الدراسات المنشورة المتعلقة بأبحاث التحلية باستخدام الطاقة الحرارية الشمسية في ليبيا، بالإضافة إلى وصف موجز لأهم تقنيات التحلية الحرارية. أظهرت هذه الدراسة أن هناك عدد قليل من المشاريع الريادية غير المكتملة للتحلية باستخدام الطاقات المتجددة. وأوضحت هذه المراجعة كذلك أنه توجد مشاريع تجريبية قليلة غير مكتملة في تطبيقات التحلية باستخدام الطاقات المتجددة.

الأنشطة البحثية في مجال الطاقات المتجددة خصوصا الطاقة الشمسية الحرارية المستخدمة في تحلية المياه محدودة جدا ولا تعطي فكرة متكاملة عن إمكانيات مختلف تقنيات تحلية الطاقة الشمسية الحرارية. ولكن معظم الدراسات التجريبية الحديثة تشير إلى إمكانية استعمال محطات القدرة الشمسية التركيبية لتغطية معظم الطلب المستقبلي من المياه في ليبيا بحلول سنة 2035م. نحتاج لكثير من الجهود لإجراء بحوث حقيقية لوضع خطة استراتيجية لمواجهة العجز المائي في ليبيا من خلال التحلية باستخدام الطاقات المتجددة والتقليدية ..

Keywords: Desalination, Solar Energy, Fresh water, Renewable energy, Solar Thermal

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1. INTRODUCTION

About 75% of earth's surface is covered by water. Unfortunately, about 97.5% of this water is salt water present in seas and oceans. Only, about 2.5% of it, is fresh water contained in underground and surface waters of which 80% is frozen in glaciers. The rest percentage of all fresh water is underground in deep and hard to reach aquifers. Only 0.5% of the total fresh water available contained in the lakes and rivers [1].

Lack of fresh water is one of the main problems that affect many countries around the world. In arid areas, potable or fresh water is very scarce and the establishment of a human habitat in these areas strongly depends on how such water can be made available [2]. Water shortages involve more than 80 countries and 40% of the world population [3]. There are 1.1 billion people without adequate drinking water. Based on forecasts for 2020, it is expected that population around the world will be reached 7.5 billion, over 60% of population will be exposed to water shortages. This is because of the population growth, the higher consumption of water associated with rising standards of living, and increased economic activities. Moreover, common use of unhealthy water in developing countries causes 80-90% of all diseases and 30% of all deaths.

Water scarcity is a growing issue worldwide. It results when the local fresh water demand is similar in size to the local fresh water supply. Figure 1 shows regions of the world in which water withdrawal approaches the difference between evaporation and precipitation, resulting in scarcity [4].

Desalination technologies play an increasing role in bridging the water gap in many countries in the world. It is defined as a water-treatment process that separates salts from saline water to produce potable water or water that is low in total dissolved solids (TDS). In 2008, seawater desalination accounts for 67% of production, followed by brackish water at 19%, river water at 8%, and wastewater at 6% as shown in Figure 2 [5].

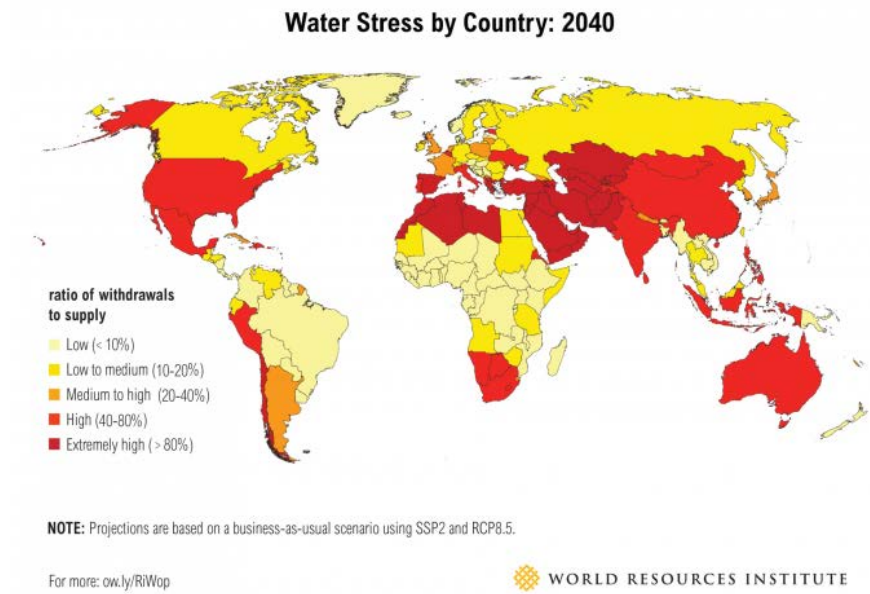


Figure (1). Regions of water stress [4].

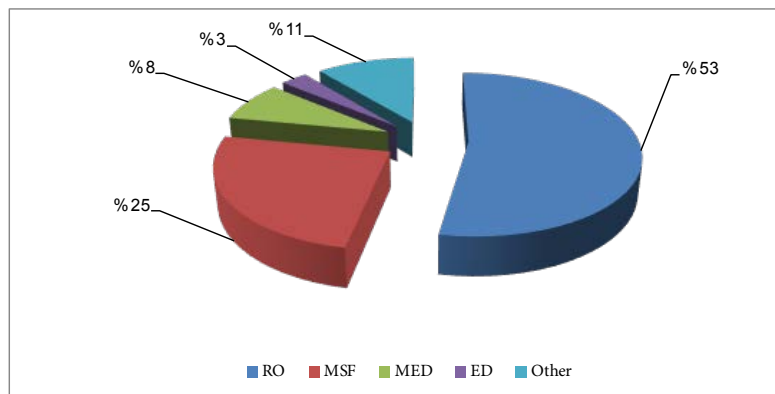


Figure (2). Worldwide feed-water percentage used in desalination [5].

There are approximately over 23,000 desalination plants operational worldwide, with a total operating

capacity of 85 million m³ per day, with 53% of them in the Middle East [6]. In the Middle East and North Africa (MENA) region, the shortage of water is approximately 9.3 billion m³ will be met mostly through desalination by 2050 [7]. However, the desalination is considered the most energy-intensive water production technique. It consumes at least 75.2 TWh of electricity per year, equivalent to around 0.4% of global electricity consumption. Most of the energy required for desalination presently comes from fossil fuels, with less than 1% of capacity dependent on renewables [8]. Energy is the largest single expense for conventional desalination plants, representing as much as half of the production cost [9].

Major desalination processes consume a large amount of energy derived from oil and natural gas as heat and electricity, while emitting harmful CO₂ gas. Solar desalination has emerged as a promising renewable energy-powered technology for producing fresh water [10].

Solar, wind, wave, geothermal and even nuclear sources could provide a viable source of energy to power both seawater and the brackish water desalination plants. Seawater desalination in itself is an expensive process, but the inclusion of renewable energy sources and the adaptation of desalination technologies to renewable energy supplies can in some cases be a particularly less expensive and economic way of providing water [11].

Libya lies in North Africa region where participation rates are very low and fresh water sources are too limited. Libya is in one of the driest regions of the world with an annual rainfall ranging from just 10 mm to 500 mm, and only 5% of its land receives more than 100 mm annually [12]. It is estimated that in 2005 the total water consumption is 4.98 km³ divided in different sectors, 78% agriculture, 12% urban and 10% industrial [13]. The municipal water consumption per capita is grew in 2010 to over 450 liters per day. The share of main sources of domestic water supply in 2015 comes from man-made river (MMR) with 62.2%, local well-fields with 29.95% and 7.85% from desalination. Therefore, seawater desalination is the most practical resort to overcome the issue of fresh water shortage. The country's population has tripled since 1950s. As a result of the population growth and the improvement of living standard, the country is confronted with a severe lack of water resources. Water deficits of about 1.154 to 4.339 km³ have been estimated for the years 1998 and 2025, respectively [14]. General Water Authority in Libya in its report in 2006 estimated the water deficit with 1 to 1.2 km³ in 2025 [13]. Another study expected the shortage in fresh water supply will reach to 3.65 km³ by 2050 [15]. There is an urgent need of addressing this problem properly to avoid serious impact on the sustainability of the development of the country.

Libya lies in the region with the highest solar radiation areas in the world. Therefore, solar thermal desalination is a vital option in providing the future demand of deficit fresh water.

This review focuses on the most available studies that conducted on the Libyan environment concerning solar thermal desalinations.

2. SITUATION OF DESALINATION IN LIBYA

Desalination will play a significant role in closing the water demand gap in Libya. A presentation given by Ministry of Utilities of Libya about the current and future source of water in Libya have shown that the demand to close the water demand gap using desalination will increase from 8% in 2009 to 40% by 2015 as shown in Table 1 [16].

Currently there are eight desalination plants operated by General Desalination Company of Libya (GDCOL) with total capacity 140,000 m³/day. There are other desalination plants operated by General Electric Company of Libya (GECOL).

Table (1). Water sources of Libya

	Source	MMR	Ground Wells	Desalination plants	Total
Actual	(m ³ /day)	955,00	594,600	140,000	1,689,000
2009	%	57%	35%	8%	
Estimated	(m ³ /day)	1,600,000	740,000	1,600,000	3,940,000
2010 -2015	%	40%	20%	40%	

MMR: Man Made River



Figure (3). General view of Zuara and Sussa desalination plants each 40,000 m³/day.

3. SOLAR DESALINATION PROCESSES

Solar energy driven desalination is becoming more feasible because it uses renewable energy and does not affect the environment negatively compared with other conventional oil consuming technologies. Solar water desalination systems refer to water desalination plants which use solar energy to drive those systems. These systems could be classified based on driving power, into two main categories: direct solar desalination systems and indirect solar systems [17].

3.1 Direct solar desalination

It is also called solar distillation systems or solar stills. In this category the desalination unit completely operated by thermal solar energy independently of any other source of energy. The operation principle of these systems is based on phase change or evaporation and condensation phenomena which simulates the rain formation process which occurred naturally in the environment. The seawater is evaporated by using thermal solar energy. Then a condensation of this vapor occurs on a cool surface to produce the freshwater [18]. In the solar stills the saline water enters a closed container covered by a glass surface. Solar radiation passes through the glass cover to heat the water and generates vapor. Consequently, this vapor condenses on the internal surface of the glass cover leaving all contaminants, microbes and salt behind in container. Finally, the condensed freshwater is collected and stored in another clean container [19]. In these systems, the desalination process occurs in the solar collector itself. In other words, the solar collector and desalination unit are the same unit. The solar distillations systems can be passive which could operate without any assistant from external source of heat such as solar collector or active which is passive system supported by external

heater to enhance evaporation process [17]. The design of solar distillation systems can be generally grouped into four classes: Basin stills, Wick stills and Diffusion stills.

3.1.1 Basin solar stills

The simple basin type solar stills generally consist of a basin, transparent glazing, distillate trough and thermal insulation to reduce heat losses. Figure 3 shows the schematic diagram of a simple single slope basin. This device has low efficiency and low water productivity due to the ineffectiveness of solar collectors to convert most of the energy they capture, and to the intermittent availability of solar radiation. For this reason, direct solar thermal desalination has limited small capacity units. Single basin stills have low efficiency, generally below 45%, and low productivity (4–6 lit/m²/day) due to high top losses. Double glazing can potentially reduce heat losses, but it also reduces the transmitted portion of the solar radiation [17]. The advantages and disadvantages of basin solar stills can be summarized as follows:

- Simple technology, easy to install and easy to operate, which does not required professional skills for operation.
- Can be used anywhere due to low maintenance requirement.
- Requires frequent flushing to avoid salt concentration in the basin.
- Low productivity of approximately 3-4 Lit/m² /day.
- Low thermal efficiency between 35%-50%.
- Received less solar radiation due to the horizontal surface of saline water.
- High capital cost required, but it is economic due to a low operation cost to provide drinkable water.
- Needs large surface area for installation and is very sensitive to the weather conditions.
- The transparent covers need continuous cleaning to remove dust accumulation.

3.1.2 Wick solar stills

The wick type solar stills have been developed to avoid some disadvantages of basin type stills. The wick stills consist of a glass cover, evaporating blackened wick or jute cloth, which represents the liquid surface, see Figure 3 [20]. Wick solar still uses the capillary action of fibers to distribute feed water over the entire surface of the wick in a thin layer. This allows a higher temperature to form on this thin layer. Insulation in the back of wick is essential. In a multiple-tray tilted still, a series of shallow horizontal black trays are enclosed in an insulated container with a transparent glazing on top. The feed-water supply tank is located above the still, and the vapor condenses and flows down to the collection channel and finally to the storage. The concentrating mirror solar still uses a parabolic mirror for focusing sunlight onto an evaporator vessel. The water is evaporated in this vessel exposed to extremely high temperature. This type of still entails high construction and maintenance costs [20,21]. The advantages and disadvantages of wick solar stills are:

- Higher water productivity of about 20%-50% more than in conventional type still.
- These need reflectors to increase the productivity.
- They require a continuous feed of water.
- Such stills need regular cleaning of contamination due to the surface nature of wick.
- They receive more solar radiation due to inclination of evaporation surface.

- A small mass of saline water leads to a higher temperature and rapid evaporation.
- Higher thermal efficiency by nearly 4% and lower cost compared with basin type.
- Natural feeding by capillary action of fiber.

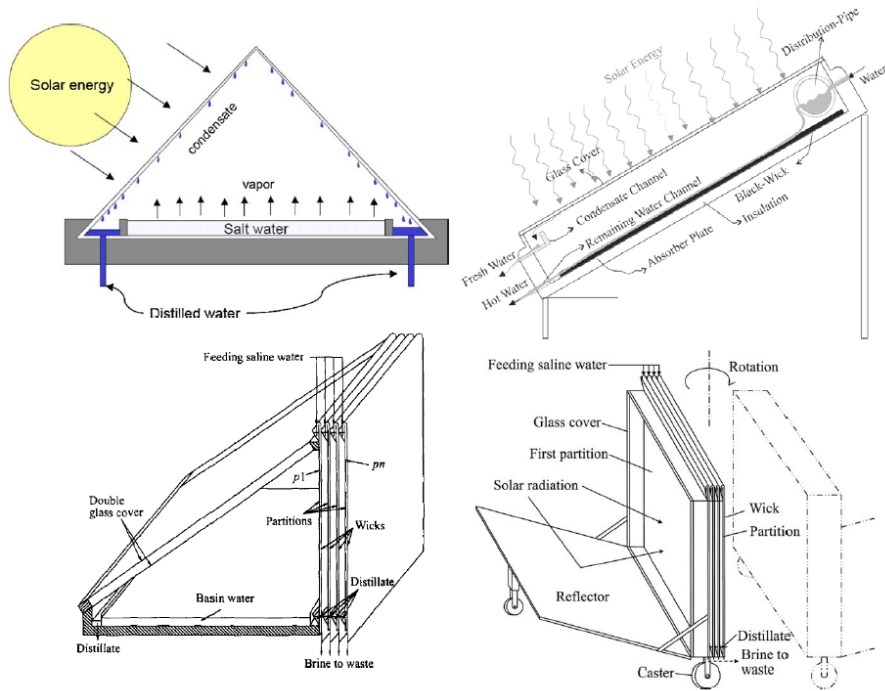


Figure (4). Schematic diagram of solar distillation systems [19].

3.1.3 Diffusion solar stills

The multiple-diffusion solar still has good potential due to its high productivity. This type consists of two units: the first one is a solar reflector or a basin with a built in solar collector. The second unit represents the solar still which consists of a vertical glass cover and number of vertical and parallel partitions covered by wetted wick with small gaps between partitions, see Figure 3 [20]. The operation principle is that after the evaporation starts in the horizontal basin the major amount of condensation occurs over the vertical glass cover due to its low temperature compared with the upper one. The latent heat of condensation diffuses to the first partition which stimulates further evaporation, from the wetted wick, and causes condensation on the back of the partition. Continually, this process progresses on to the last partition [19]. Alternatively, in the case of the solar reflector, the first partition receives the solar radiation directly from the sun and the reflected radiation from the reflector starts the distillation process. The advantages and disadvantages of diffusion solar stills are:

- They have a simple design and are easy to operate.
- They have high productivity which is greater than in the other types of stills.
- The productivity is highly dependent on a number of partitions and the gaps between partitions.

- Exhibits high thermal efficiency which is greater than in the other types of still.
- More flexible and can be easily integrated with tracking system to provide better angles for both the still and the reflector.
- The gap between partitions should be optimal so its value should be carefully and critically controlled.

3.2 Indirect solar desalination

The indirect solar desalination systems consist of two separate units: a solar collection unit to receive solar radiation and transform it into thermal energy and then transfer that energy via a heat exchanger to a desalination unit. There are different designs and configurations which include solar humidification and dehumidification processes and solar assisted conventional desalination systems.

3.2.1 Solar humidification-dehumidification desalination

The humidification-dehumidification (HD) systems consist of a humidifier (evaporator) represented by a solar collector or absorber and a dehumidifier (condenser) with a cool surface. The working fluid in these systems is air and the operational principle depends on the capability of dry air to carry a significant amount of water vapor, and on the phenomena of increasing this capability by elevating the temperature of the air using any heat source, for example, solar energy. Generally, when dry air comes into contact with seawater in the evaporator, it will be saturated by a certain quantity of vapor. Then, this humid air is circulated naturally or forcefully, for example by the blower, to pass over the condenser, a cool surface, and thus extracting the freshwater [22]. The solar HD systems conventionally consists of a humidification unit, usually it is a solar collector, and a dehumidification unit. There is a stream of air between them to force the water vapor towards the condensation area. HD is classified into two types: the first type is with open water/closed air cycle in which the air is circulated between a humidifier and a condenser; the second type is with close water/open air cycle in which the water is circulated while the air enters and leaves the system Figure 4 [18]. The advantages and disadvantages of solar humidification dehumidification processes include:

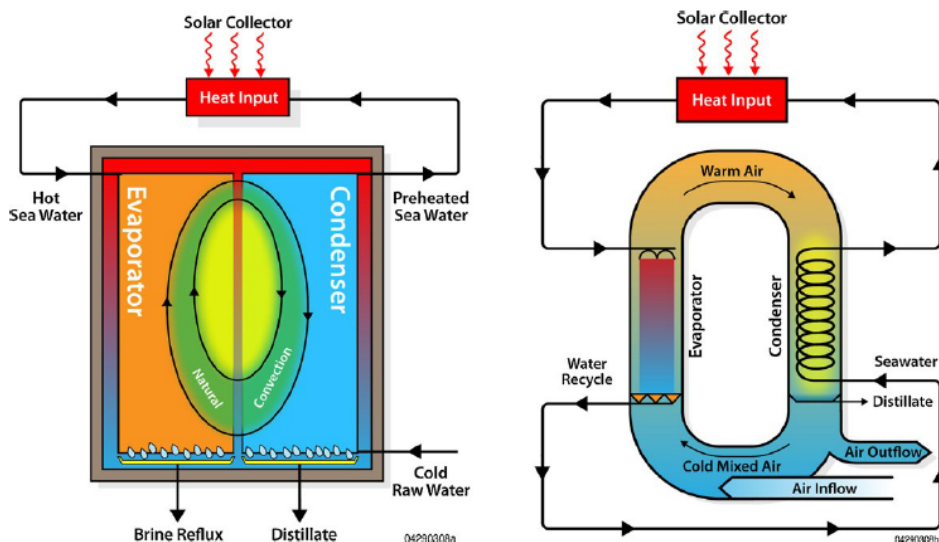


Figure (5). schematic diagram of solar HD process (a) closed cycle (b) open cycle [18].

- Flexibility in capacity, simplicity of design and moderate installation and operational cost.
- Most of latent condensation heat is easily used for preheating the feed water which increases the overall efficiency.
- Operation at the low temperature and the working fluid is air leading to the reduction of corrosion and scaling processes in the solar heaters.
- These need more energy to satisfy the power requirement for water pumping and air circulating.

3.2.2 Solar energy assisted conventional desalination

The solar energy is used to support conventional desalination plants. The conventional desalination systems could be thermal desalination systems such as multi-stage flash (MSF), multi-effect desalination (MED) and vapor compression (VC); in which thermal solar energy is generated utilizing solar field and used to support the operation of conventional systems. The second type of the conventional desalination technology is membrane processes which are based on the properties of special types of membranes to separate salts and other contaminants from the seawater. This type uses Photovoltaic (PV) technology or solar organic Rankine cycle to produce electricity from which is necessary to drive pressure pumps to push the saline through the membrane [18].

3.2.3.1 Multi-stage flash desalination

The multi-stage flash desalination (MSF) is the most mature and widely applied desalination technology which has high productivity and is economically competent. The MSF technique is based on the flash process of hot saline water to produce vapor. In this technology the saline water, after being heated up by solar collectors, is rapidly discharged into a number of stages with pressures gradually reducing from stage to stage. This sudden decrease in pressure and the relatively high temperature results in fast evaporation (flash) of a fraction of the hot water. Heat exchangers are used in this method to condensate the vapor and produce freshwater. The heat released during condensation is used to preheat the saline water, see Figure 5 [23]. The advantages and disadvantages of solar MSF desalination are:

- Simple processes with high performance.
- Suitable for large capacity water production due to the high productivity.
- Long operational life and low scale formation due to use of flashing rather than boiling.
- High quality production and minimal pre-treatment of the feed water.
- Ability to be combined with power generation plants.
- Needs a thermal storage tank for stable operation due to necessity of maintaining the accurate pressure gradient required in the different stages.
- Large initial capital investment and project area required to build the plant.
- Sensitive to corrosion issues and has a low recovery ratio.
- Requires high technical skills and regular maintenance.

3.2.3.2 Multi- effect desalination

The multi-effect desalination (MED) units as shown in Figure 6 operate on the principle of reducing the chamber pressure at each successive stage, allowing the feed water to undergo multiple boiling without having

to supply additional heat after the first stage. In this unit, steam is fed into a series of tubes, where it condenses and heats the surface of the tubes and acts as a heat-transfer surface to evaporate saline water on the other side. The energy used for evaporation of the saline water is the heat of condensation of the steam in the tube. The evaporated saline water is fed into the next, lower-pressure stage where it condenses to fresh-water product, while giving up its heat to evaporate a portion of the remaining seawater feed[5]. The advantages and disadvantages of solar MED desalination can be summarized as:

- Less sensitive to corrosion and scale formation compared to MSF.
- The process can be carried out without a large number of operational staff.
- High quality water production and easier pre-treatment processes.
- High energy consumption, high capital and operational costs.
- The product water needs to be cooled before being used.

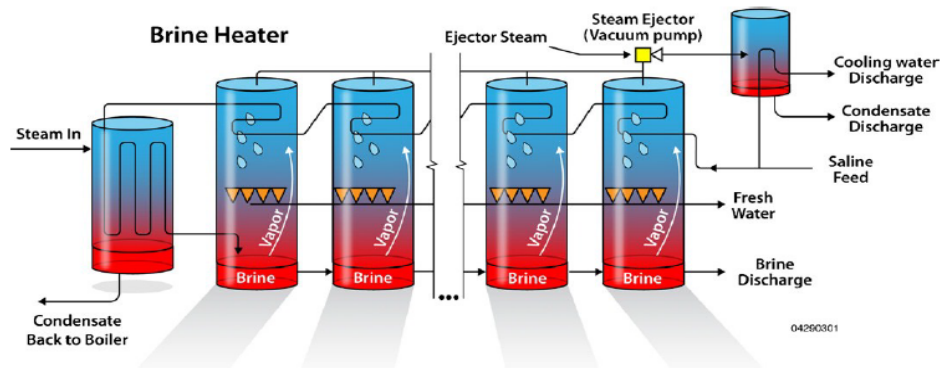


Figure (6). Multi-stage flash desalination system [18].

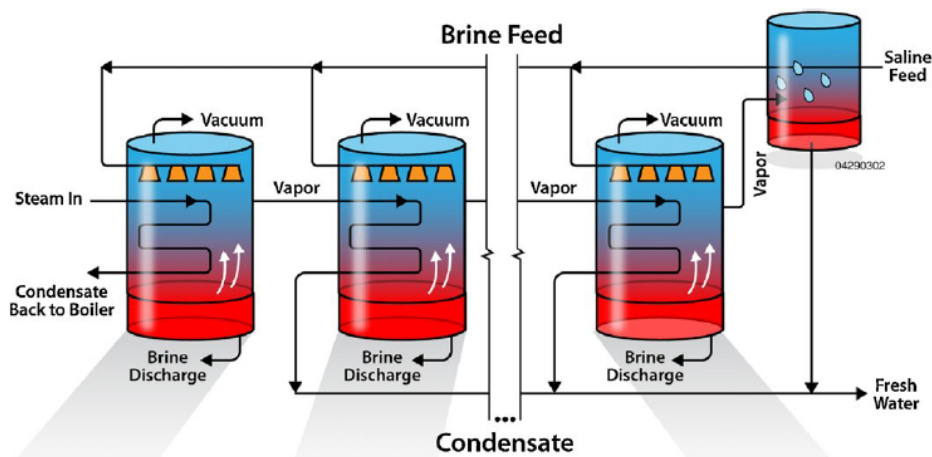


Figure (7). Multi-effect desalination system [18].

3.2.3.3 Vapor-compression desalination

The vapor compression desalination (VC) distillation process is generally used for small- and medium-scale seawater desalting units. The heat for evaporating the water comes from the compression of vapor, rather than from the direct exchange of heat from steam produced in a boiler. A venture orifice at the steam jet creates and extracts water vapor from the main vessel by creating a lower ambient pressure in the main vessel. The extracted water vapor is compressed by the steam jet. This mixture is condensed on the tube walls to provide the thermal energy to evaporate the seawater being applied on the other side of the tube walls in the vessel [23]. The VC desalination technology is subdivided into two categories: in the first type, the mechanical vapor compression (MVC) occurs using a mechanical compressor driven by electric power produced from solar PV panels, see Figure 7. The second type is based on the thermal vapor compression (TVC) using a motive steam with high velocity in the nozzle to extract water vapor and create low pressure in the evaporator [3]. The advantages and disadvantages of solar VC desalination are:

- Low working temperature which reduces risks of scale formation and corrosion.
- High risk of corrosion on compressor blades due to pressure of brine in the vapor.
- Restricted plant size because of the compressor capacities.
- Requires start-up heating devices to create vapor.

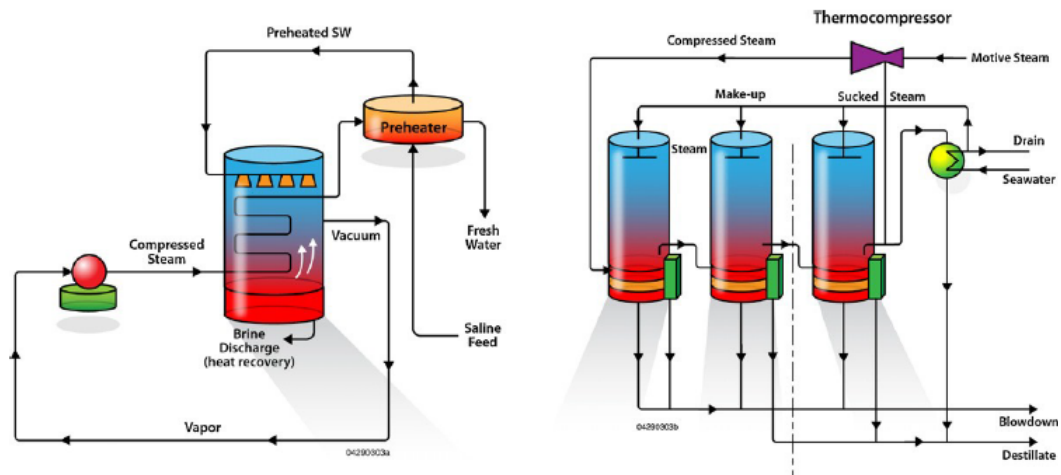


Figure (8). Vapor compression desalination (a) mechanical (b) thermal [18].

3.2.3.4 Reverse Osmosis Desalination

The operation principle of the reverse osmosis process (RO) is based on separation of water by a semi-permeable membrane at which time, the saline water take place in one side and freshwater on the other side of the membrane. Next, the saline water has to be pressurized to exceed the natural reverse osmosis pressure which is about 50-80 bars to produce a feasible amount of freshwater. At this pressure the saline water starts to pass through the membrane leaving the concentrated brine behind in the saline water side, see Figure 8 [3]. The energy required to run a RO plant is mainly needed to drive the high pressure pumps and create the sufficient pressure. This energy could be produced using PV technology or thermally by solar Rankin cycle.

4. RESEARCH ACTIVITIES

Numerous number of research were carried-out dealing with conventional desalination technology and applications in Libya [24,25,26,27,28,29,30]. However, only small amount of research related to use renewable energy resources in the desalination technology were found in the literature conducted in Libya. The most available published work is presented here.

4.1 Theoretical and Experimental Work

Srbet et al [32] conducted an experimental work on two identical solar stills, but one of them was coupled with flat plate solar collector. The dimension of the basin is 170 cm x 60 cm (1.02 m²) and the flat plate collector aperture area is 1.566 m². They were oriented to due south with tilt angle of 23°. The experiments were carried out at the Center for Solar Energy Research and Studies, in Tajoura, August 2009, and various parameters were measured. The test was conducted using seawater with a salinity of 35,000 ppm, and the depth of the water in the basin was kept at 60 mm. Fresh water production of the coupled still was recorded to be 6.6 Lit/day which is higher than that of single still by 55.84% and the total daily radiation was 26.738 MJ/m². The maximum daily efficiency of the single still was 14.48% while for coupled still was 24.18%.

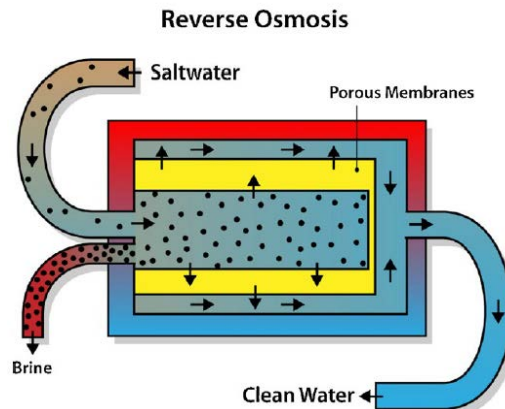


Figure (9). Reverse osmosis desalination system [18].

Shuia and El-Agouz [33] have studied experimentally the effect of absorber surface of the single-basin solar still on the system performance. Different absorber materials were used to enhance the solar still productivity. The materials used in the study are steel and aluminum with and without black painting and rubber. Two locally manufactured identical solar stills are used. The results have shown that painted black rubber gives the best performance compared to others. The average enhancement in the daily productivity was about 50% for the rubber absorber compared with black painted aluminum absorber, and over 43% compared with black painted steel absorber.

Many studies estimated the demand for water by 2050 in Libya, for instance, Moser [31] estimated the demand by 6.2 Bm³/y and the CSP and desalination could cover 2.8 Bm³/y. AQUA-CSP report estimated the demand in Libya in 2050 would be 9.4 Bm³/y and the share of CSP-desalination is 7.4 Bm³/y. The analysis confirms the economic potential of CSP-desalination to be large enough to solve the threatening MENA water crisis. On the other hand, it shows that the process to substitute the presently unsustainable over-use of groundwater by solar powered desalination will take until 2025 to become visible [34].

The largest medium-term market volumes for CSP-desalination until 2020 were found in Egypt (3.6 Bm³/y), Saudi Arabia (3.4 Bm³/y), Libya (0.75 Bm³/y). All countries in North Africa will experience a reduction of their water demand growth rates until 2050. The per capita consumption is presently highest in Egypt and Libya (about 1000 m³/cap/y). The analysis of water deficits shows that there is a pressing need for new, nonconventional, sustainable water sources in many countries of the MENA region. The hot spots can be found in North Africa (mainly Egypt and Libya). North Africa will be the largest future market for CSP desalination, with Egypt and Libya being the main candidates for installing large plant capacities [34]

The North Western Sahara Aquifer will suffer similar consequences if following a business as-usual strategy. Libya has already initiated a significant withdrawal of fossil groundwater with the Great Man-Made River Project. According to /UNESCO 2006/, current extraction from the aquifer amounts to about 2.6 Bm³/y, which theoretically would allow a continuous extraction for about 500 years. However, taking into consideration growth of demand and following a business-as-usual scenario, about 27 % of the reserve would have been withdrawn by 2050, while the AQUA-CSP reference scenario leads to an extraction of only 6.8 % by that time.[34]

Bshina [35] suggested solar /wind desalination still for day and night production of distil water. Vertical axis wind rotor is used with the solar still. The study has shown that the system can produce 8 (lit/m²/day) day and night. However, the study considered overestimated values of solar insolation and wind speeds.

Nassar et al. [36] have designed and manufactured solar desalination system working on the basis of evacuation. The solar energy is concentrated by means of concave mirror, and the still is located at the focus. The still works under vacuum of 562.5 torr (25 kPa absolute) to reduce the normal boiling point of the income water. A condenser is used to condense the outlet vapor. The experiment was conducted during the period from 15 April to 15 May 2003. The water productivity of the offered still was found about 20 Lit/day per unit area of the reflector. The experimental results showed a significant improvement of the productivity of desalinated water, about 303% compared with the other thermal solar stills. Moreover, the performance ratio increases 900% more than the roof-type desalination solar systems.

There are a number of studies [37,38,39, 40,41] related to desalination using renewable energy technology such as PV and wind energy.

Bashir et al [42] and Elmegadmi [43] have designed and manufactured solar still with multi-story, the still consists of 6 story (layer), the first was made of Aluminum and others were made of stain-less steel. The layer feed by capillary feature through cloths adhered behind each layer. The studies have shown such and a developed still can produce 20 liter of distal water during 8 hours under indoor sun simulator. The still is enhanced by improving the feeding system through using valves and irrigation spray instead of the old medical needles to control water flow rate. The study has shown that using irrigation spray is easier to install and to control. The study also used different types of cloths instead of using cotton. Al-Mesalati et al [44] have conducted experimental work with DIFICAP device which is a sort of multi-story still with 6 stories. The results showed the maximum recorded production is only 0.707 liters, and the system production is improved at inclination of 30°.

Mahdi [45] has investigated theoretically solar distillation using a wick-type solar still, and experimentally by Mahdi et al.1990 [46]. Mahdi et al.1992 [47] investigated the effect of intensification of the solar radiation incident on the wick-type solar still performance. A tilted flat plate wick-type solar still and a V-trough concentrator were designed, constructed. The solar still performance was investigated with and without the concentrator. The designed concentrator has an expected concentration factor for beam radiation of about 1.68.

The results have shown that by increasing the inlet water flow rate from 3.2 to 4.5 kg/m².hr when the solar concentrator was used, the still efficiency is decreased. However, the efficiency has been increased from 53.4 to 63.6 % daily.

Experimental and theoretical investigations of the performance of a novel small scale solar thermal water desalination system are carried out by Mahkamov and Belgasim [48,49,50]. This system is a combination of a fluid piston engine and small desalination unit powered by evacuated tube solar collector. An experimental prototype of the system was installed at Northumbry University laboratory, UK and tested under climate condition of Benghazi city, Libya by using solar simulator made of halogen floodlights.

The theoretical part the thermodynamic mathematical model of the system was developed. In the calculation scheme, the internal circuit of the desalination unit was split into several control volumes. The lumped parameter mathematical model consists of the differential equations of energy and mass conservation was written for each of the control volumes. The model accounted for heat and mass transfer processes taking place during water evaporation and condensation under cyclic variation of the pressure and temperature inside the system during the engine's operation. Solution of the set of governing equations was obtained by developing dynamic Simulink code. The results produced information on variation of temperatures and pressure inside the system over the thermodynamic cycle and on the water desalination capacity of the unit.

In the experimental part of this project the system was equipped by pressure, temperature and liquid level sensors connected to a data acquisition system to record experimental characteristics of the operation of the system. After validation of the theoretical model with the experimental results, a parametric analysis and optimization study using the Genetic Algorithm method for the rational design parameters were conducted. Resultantly, both the theoretical and experimental investigations demonstrated that this novel system has noticeably higher freshwater production capacity when compared to conventional solar stills.

Abdunnabi and Ramadan [51] conducted a simulation study in an attempt to make the best use of readily available components (90 vacuum tubes collators, 4 storage tanks) to operate the MSF desalination unit with field of solar thermal collectors. Several configurations of collectors and tank arrangements were designed and examined through the use of simulation software, TRNSYS. The study has shown that the layout-3 (two 500 liters storage tanks each of them connected with 9x5 vacuum tube collectors) gives the best performance with an annual solar fraction over 77% at load temperature of 70 °C with flow rate of 2500 lit/hr, and over 68% at load temperature of 80 °C and 1640 litres of fresh water with salinity less than 100 ppm for working condition of 8 hours daily.

The study has also shown that operating the desalination plant for 24 hours a day reduces the solar fraction of the solar collector field to 25%.

El-Sayed et al [52] studied two desalting schemes for the irrigation of the equivalent of 1200 hectares in single-cropping in the 12000 agricultural hectares of Wadi El-Hai, 60 km South-west of Tripoli. The schemes are: one utilizing the electrodialysis process with suitable water supply and distribution systems and the other utilizing in-situ solar stills in a drip-irrigation system. The economic indices for prices and land productions, benefits are likely to exceed costs for an average products value of 47 cent / kg with the electrodialysis scheme and of 115 cent / kg with the solar scheme. The study concluded that solar scheme might become competitive with electrodialysis in case of the solar stills can be manufactured at \$ 10/m² pool area (3 L.D./m²) with a yearly average performance of 3.5 L/m² day.

Part from work in the STAGE-STE project granted from the European Commission grant agreement number 609837, task 6.2.2 Design of CSP plants for desalination in Libya. The study reported different water sources currently used and those have future prospective. The potential of using solar energy in desalination

is also presented in the report. The performance of solar desalination in Libya, a 50 MW CSP plant integrated with MED systems is proposed to operate under North Libyan climate conditions. The 50 MW parabolic trough hybrid operation (electricity and desalination) plant has been chosen, because the parabolic trough is the most commercial and mature CSP technology. The study have shown that in the summer that the plant produces electricity at full load (35MW) for about 19 hours per day and fresh water production occurs at a rate of 750m³/hr over a 7-hour period per day. In the winter, the average net electricity production drops to 15MW for about 6 to 7 hours per day while productivity during those hours is about 750m³/hr. The average energy consumption per volume of water produced is approximately 0.05 MWh/m³ [53]

4.2 Strategies and Policies

As a result of the population growth and the improvement of living standard, the country is confronted with a severe lack of water resources. Water deficits of about 1.154 to 4.339 km³ have been estimated for the years 1998 and 2025, respectively [54]. General Water Authority of Libya in its report in 2006 estimated the water deficit would be 1 to 1.2 km³ in 2025 [13]. This deficit would be confronted by using desalination of sea water.

In a study conducted in the European Commission Seventh Framework Programme MED-CSD Project [55], the concentrated solar power is expected to play a vital role in seawater solar desalination in the medium and long term plan as shown in Figure 9.

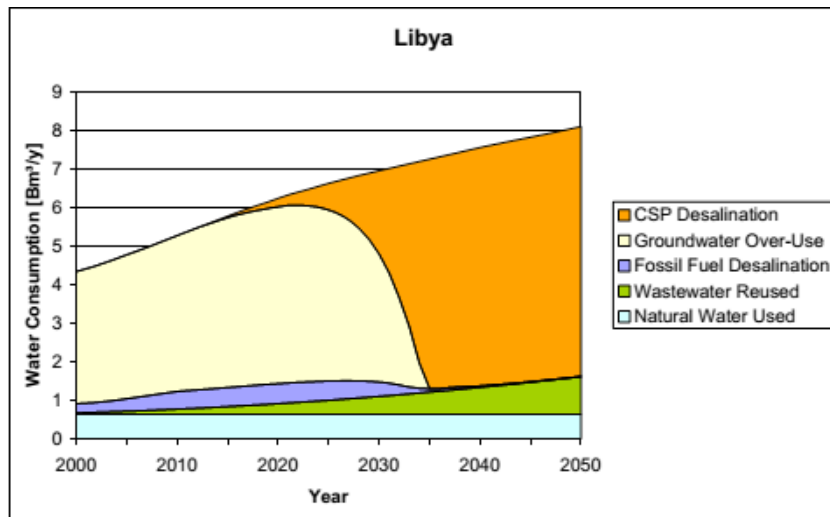


Figure (10). Scenario of water supply in Libya [55]

Another study has shown the tactical options of covering the expected demand in fresh water in Libya by 2050 as shown in Figure 10 [15]. It is very clear that a great portion of the demand will be covered by desalination-CSP as the cost of using fossil fuels in desalination is more expensive than using desalination-CSP at that time.

5. PILOT PROJECTS

The center for Solar Energy Research and Studies constructed two small scale pilot projects

5.1 MSF Operated by Solar Pond

A 5 meter cubic per day Multi-Stage Flashing (MSF) desalination unit with 14 stages available at the Center was used in this project, Figure 11. This plant is coupled with the solar pond of TESP as shown in Figure 12. The technical specifications for this plant are shown in Table (4). The plant is capable to work over a wide temperature range of low grade thermal energy input without loss of efficiency. The maximum design working temperature is 80 °C, and the preferable range of operation is between 70 – 80 °C. [56]

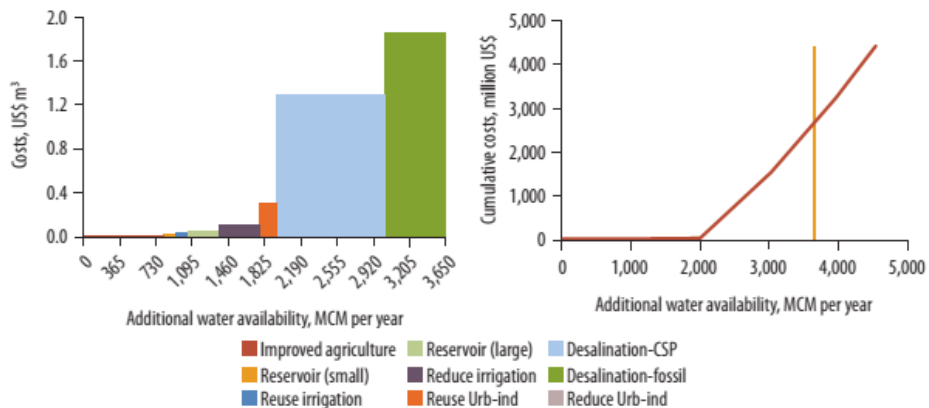


Figure (11). Ranking and magnitude of tactical options to fill the water gap by 2050 [55]



Item	Value
Average daily production of fresh water	5 m ³ /day (0.208m ³ /hr)
Max working temperature	80 ° C
Sea water temperature	20 ° C
Thermal energy consumption	15.6 kW
Specific consumption of electric power	4.8 kWh/m ³
Rate of flow of sea water (nutrition and cooling)	2.3 m ³ /hr
Flow rate of saline solution	2.1 m ³ /hr
Concentration of the Mediterranean sea waters	35,000 ppm.
Specifications of desalinated water	< 100 ppm

Figure (12). A view of the MSF Desalination unit and its technical specification.

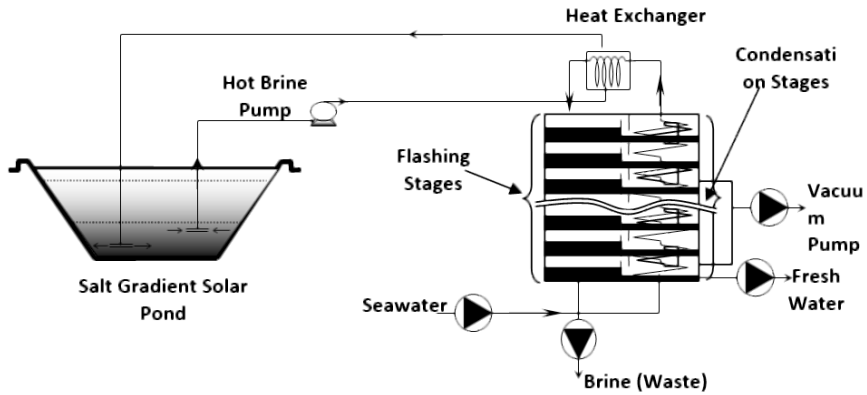


Figure (13). Schematic drawing of MSF Desalination Unit coupled with TESP.

5.2 MSF OPERATED BY VACUUM TUBE COLLECTORS

Due to the stopping of the work in the solar pond project, an idea stems to run the existing MSF desalination unit by using vacuum tubes collectors. The project started in 2013, number of 90 vacuum tubes collector of type DRC 10 and four storage tanks and five pump station are imported to run the project. Most of the civil work at the site is executed as shown in Figure 13. The other need components of the project including hydraulic system, measuring and control system are defined.

The work in this project is stopped due to financial problems related to the political instability in the country.



Figure (14). MSF desalination operated by vacuum tubes collector project

6. CONCLUSION

Libya is considered one of the countries under fresh water stress in the world. Over 92% of the water demand in residential, industrial and agricultural comes from groundwater sources; about 8% of the freshwater is covered by desalination plants. Libya is considered the 7th from the capacity size of water produced by desalination process. All the desalination plants are powered by conventional sources of energy and no renewable energy sources for water desalination.

A lot of research activities related to conventional desalination process and technology are carried-out in Libya. However, limited studies were devoted to renewable energy powered desalination plants. The main focus in this review is to gather all studies and projects on solar thermal desalination in Libya. The most published work is discussed briefly in this review. The preliminary findings of using solar desalination are encouraging for further investigations and implementations. A lot of studies refer to the high potential of using CSP desalination for future utilization to cover the gap of water deficit.

7. REFERENCES

- [1]. P.V. Kumar, A.K. Kaviti, O. Prakash, K.S. Reddy "Optimization of design and operating parameters on the year round performance of a multi-stage evacuated solar desalination system using transient mathematical analysis", *international Journal of Energy and environment*, Vol. 3, Issue 3, pp 409-434, 2012.
- [2]. S. A. Kershman, "25 year of experience in operating thermal desalination plants", *Desalination* 136, pp141-145, 2001.
- [3]. S.A. Kalogirous, "Seawater desalination using renewable energy sources", *Progress in Energy and Consumption Science*, 31, pp 242-281, 2005.
- [4]. J. H. Lienhard, M.A. Antar, A. Bilton, J. Blanco, G. Zaragoza "Solar Desalination", *Annual Review of Heat Transfer*", Chapter 9, pp 277-345, 2012.
- [5]. Al-Karaghoul Ali A. and L.L. Kazmerski, "Renewable Energy Opportunities in Water Desalination", *Desalination, trends and Technologies Book*, Chapter 8, Feb., 2011.
- [6]. Clayton R, "Review of current knowledge desalination for water supply", 3th edition, *Foundation for water research*, Buck, UK, 2015.
- [7]. IRENA, "Renewable Energy in the Water, Energy & Food Nexus", www.irena.org/Publications, 2015.
- [8]. *Water desalination using renewable energy*, Technology Brief IRENA and IEA-ETSAP, 2012
- [9]. Andrew Herndon, *Energy Makes Up Half of Desalination Plant Costs: Study*, BLOOMBERG (April 17, 2018, 16:45 PM), <http://www.bloomberg.com/news/2013-05-01/energy-makes-up-half-of-desalination-plant-costs-study.html>.
- [10]. Said Al-Hallaj, Sandeep Parekh, M. M. Farid, J. R. Selmamet "Solar desalination with humidification–dehumidification cycle: Review of economics", *Desalination*, 195, pp169–186, 2006.
- [11]. M. Goosen, H. Mahmoudi, N. Ghaffour and S. Sablani "Renewable Energies for Water Desalination", *Desalination, trends and Technologies Book*, Chapter 5, Feb., 2011.
- [12]. Mohamad Nasar, "Survey of Sustainable Development to Make Great Man-Made River Producing Energy and Food", *Current World Environment* Vol. 10(3), pp758-763, 2015.
- [13]. General Water Authority, Ministry of Agriculture "Water Situation in Libya", *Livestock and water*, 2006.
- [14]. Wheida E. and Verhoeven R., "Desalination as a water supply technique in Libya", *Desalination*, 165, pp 89–97, 2004.
- [15]. "Renewable Energy Desalination: An emerging solution to close the water gap in the Middle East and North Africa", *International Bank for Reconstruction and Development / The World Bank*, 2012.
- [16]. Ahmed Algemati, "Plan for the future water sources in Libya, Ministry of Utility", 2009.
- [17]. Qiblawey H. M. and F. Banat, "Solar thermal desalination technologies," *Desalination*, vol. 220, pp 633-644, 2008.
- [18]. Al-Karaghoul A., D. Renne & L. Kazmerski., "Solar and wind opportunities for water desalination in the Arab regions,"

- Renewable and Sustainable Energy Reviews*, vol. 13, pp 2397-2407, 2009.
- [19]. Tiwari G. N. and Tiwari A. K., "Solar distillation practice for water desalination systems: Anshan", 2008.
- [20]. A. Kaushal and Varun, "Solar stills: A review," *Renewable and Sustainable Energy Reviews*, vol. 14, pp 446-453, 2010.
- [21]. Arjunan T. V., Aybar H.S., Nedunchezian N., "Status of solar desalination in India," *Renewable and Sustainable Energy Reviews*, vol. 13, pp. 2408-2418, 2009.
- [22]. Bourouni K., Chaibi M. and Tadrist L., "Water desalination by humidification and dehumidification of air: state of the art," *Desalination*, vol. 137, pp 167-176, 2001.
- [23]. Khawaji A. D., Kutubkhanah I.K, Wie J.M., "Advances in seawater desalination technologies," *Desalination*, vol. 221, pp 47-69, 2008.
- [24]. Mohamed M. Elabbar, Farej A. Elmabrouk, "Environmental impact assessment for desalination plants in Libya. Case study: Benghazi North and Tobrouk desalination plants", *Desalination*, Vol.185, Issues 1-3, 1, pp 31-44, 2005.
- [25]. Nuri M. Eshoul, Brian Agnew, Alexander Anderson, Mohanad S. Ata, "Exergetic and economic analysis of two-pass RO desalination proposed plant for domestic water and irrigation", *Energy*, Vol. 122, 1, pp 319-328, 2017.
- [26]. Abdulmonem Elhassadi, "Horizons and future of water desalination in Libya", *Desalination* Vol. 220, pp115-122, 2008.
- [27]. Mukhtar M. Ashourm Salem M. Ghurbal, "Economics of seawater desalination in Libya", *Desalination* Vol. 165, 15, pp 215-218, 2004.
- [28]. Salem Ghurbal, Mukhtar Ashour, "Economic competitiveness of nuclear desalination in Libya", *Desalination*, Vol. 158, Issues 1-3, pp 201-204, 2003.
- [29]. Abufayed, A. A., "Performance characteristics of a cyclically operated seawater desalination plant in Tajoura- Libya", *Desalination* Vol. 156, Issues 1-3, pp 59-65, 2003.
- [30]. Abufayed A.A., El-Ghuel M.K.A., "Desalination process applications in Libya", *Desalination*, Vol.138, Issues 1-3, pp 47-53, 2001.
- [31]. Massimo Moser, Franz Trieb, Tobias Fichter, "Potential of Concentrating Solar Power Plants for the Combined Production of Water and Electricity in MENA Countries", *Journal of Sustainable Development of Energy, Water and Environment Systems*, Volume 1, Issue 2, pp 122-140, 2013.
- [32]. Srbet S.A., Jaballa T.M., Dekam E.I, "The effect of coupling flat plate collector with basin solar still", *JSESD*, Vol.1,1, pp 42-50, 2012.
- [33]. Essied M Shuia, Elsayed A. El-Agouz, "Effect of different absorber materials on the performance of basin solar still under Libyan climate conditions", *JSESD*, Vol. 2, 1, pp 1-10, 2013.
- [34]. AQUA-CSP, "Concentrating Solar Power for Seawater Desalination", Final Report, , DLR, 2007, available at: <http://www.dlr.de/tt/aqua-csp>.
- [35]. Noreddin S. Bshina, "Use of Wind And Solar Energy for Desalination of Sea or Brackish Water", *University Bulletin*, Issue No.17, Vol. 1, March-2015.
- [36]. Yasser Fathi Nassar, Saib A. Yousif, Abubaker Awidat Salem, "The second generation of the solar desalination systems", *Desalination*, Vol. 209, Issues 1-3, Pages 177-181, 2007.
- [37]. Sultan A. Kershman, Jürgen Rheinländer, b, Hansjörg Gablerb, "Seawater reverse osmosis powered from renewable energy sources - hybrid wind/photovoltaic/grid power supply for small-scale desalination in Libya", *Desalination*, Vol. 153, pp 17-23, 2002.
- [38]. Sultan A. Kershman, Jürgen Rheinländer, Thomas Neumannc , Olaf Goebel, "Hybrid wind/PV and conventional power for desalination in Libya—GECOL's facility for medium and small scale research at Ras Ejder", *Desalination*, Vol.183, pp1-12, 2005.
- [39]. Ali Mustafa A. Almaktoof, "Economical analysis of a stand-alone PV-RO system for rural areas, Zaytoonah University International Engineering Conference on Design and Innovation in Infrastructure", pp L14-1 L14-9, 2012.
- [40]. Mohamed M. Elabbar, "The Libyan experimental on the environmental impact assessment for desalination plants", *Desalination*, Vol. 220, Issues 1-3, pp 24-36, 2008.

- [41]. Alghoul M.A., Poovanaesvaran P., Mohammed M.H., Fadhil A.M., Muftah A.F., Alkilani M.M, Sopian K., "Design and experimental performance of brackish water reverse osmosis desalination unit powered by 2 kW photovoltaic system", *Renewable Energy*, Vol. 93, Pages 101-114, 2016.
- [42]. Bashir R, Ali S Elmegadmi, Fawzia A, Guma T, "Solar Still with multi-story", *Solar Energy*, CSERS, 1,1,pp 13-15, 1992.
- [43]. Elmegadmi Ali S, Fawzia A, Bashir R, "Solar Still with multi-story: development and improving feeding system", Vol.2, 1, pp 13-17, 1993.
- [44]. Al-Mesalati M, Ben Rajeb B., Mustafa, M., and Al-Zhanian, "Solar distillation by using DIFICAP device", *First Phase, Final Report*, 1995.
- [45]. Mahdi, J. T., "Transient performance analysis of a flat plate wick type solar still", *Second Exposition and Symposium for New and Renewable Energy Equipment*, Tripoli, Libya, pp25-27, May-1992.
- [46]. Mahdi, J. T.; B. E. Smith and J. Freeman," Investigation of materials for experimental wick-type solar stills", *Energy and Environment, Into the 1990s, Proceedings of the 1st World Renewable Energy Congress*, Reading, U.K. pp 23-28, Sept. 1990.
- [47]. Mahdi J.T. and Smith B.E., "Solar distillation of water using a v-trough solar concentrator with a wick-type solar still", *Renewable Energy*, Vol.5, I, pp. 520-523, 1994.
- [48]. Mahkamov K. and Belgasim B., "Experimental study of the performance of a dynamic water desalination with a fluid piston engine", *Proceedings of the 14th International Stirling Engine Conference and Exhibition (ISEC)*, pp16-18, Nov. 2009, Groningen, Netherlands.
- [49]. Belgasim B. and Mahkamov K., "Theoretical modeling of a dynamic solar thermal desalination unit with fluid piston engine", *Proceedings of the 2nd World Renewable Energy Congress (WREC)*, pp 8-11, May 2011, Linkoping, Sweden.
- [50]. Mahkamov K., Orda E., Belgasim B. and Mahkamova I., "A novel small dynamic solar thermal desalination plant with a fluid piston converter", *Applied Energy*, Vol .156, pp 715–726, 2015.
- [51]. Abdunnabi M., Ramadan, A., "Simulation Study of the Thermal Performance of MSF Desalination Unit Operating by Solar Vacuum Tube Collectors", *IASTED Proceedings*, Las Vegas, pp 12-14, Nov, 2012.
- [52]. El-Sayed Y.M., Shakshooki S.K., Jawad J.A., Matar Y., "Desalting saline ground water for agriculture", *Desalination*, Vol. 19, Issues 1–3, pp 175-188, 1976.
- [53]. Mohammad Abdunnabi, Basim Belgasim, Khaled Hossin, Ratha Z. Mathkor, Mokhtar Abaid, *Design of CSP plant for desalination in Libya, STAGE-STE Deliverable Desalination in Libya report, 2017* (http://www.stage-ste.eu/deliverables/STAGE-STE%20WP6_D6.5%20CSP%20desalination%20plant%20in%20Libya.pdf)
- [54]. Wheida E. and Verhoeven R., "Desalination as a water supply technique in Libya", *Desalination*, 165, pp 89–97, 2004.
- [55]. Nicolas Cottret, Houda Ben Jannet Allal, Franz Trieb, Enrico Savoldi, MED-CSD Project, "Combined Solar Power and Desalination Plant: Techno-Economic Potential in Mediterranean Partner countries", *European Commission Seventh Framework Programme, Grant Agreement No. 213824*, 2010.
- [56]. Agha, K.R., Abughres S.M. and Ramadan A.M., "Design Methodology for a Salt Gradient Solar Pond coupled with an Evaporation Pond", *Solar Energy*, Vol. 72, pp 447-454, (2002).