

Thermal Solar Desalination Technologies for Small-Scale Irrigation

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Abstract Water challenge in arid countries is considered one of most critical challenges facing agriculture and food systems, and is expected to grow with time. This is due mainly to the scarcity and rapid depletion of freshwater resources, and the increasing groundwater salinity. Nevertheless, these countries have generally a great solar energy potential. This potential can be best developed by solar desalination concepts and methods specifically suited for rural water supply, including small-scale irrigation, and also the protection of available water resources against overuse and pollution. The present study is concerned with the performance review of solar desalination systems that could be applied for agriculture applications in rural arid areas. Direct and indirect solar desalination technologies of solar energy based system concepts for irrigation water desalination are described and analyzed. Attempts are reported to propose precepts upon which a strategy can be formulated for introducing desalination technology for irrigation.

Keywords: arid areas, desalination, agriculture, irrigation, solar energy

1. Introduction

Arid lands today face more difficult problems than ever before. The world's sand deserts appear to be enlarging, and droughts are contributing to the economic devastation of whole nations. Arid lands suffer from the crisis. They face falling water tables and increasing groundwater salinity [1].

Nevertheless, arid lands have generally a great solar energy potential. We should learn that this potential can be best developed by concepts and methods specifically suited to supply dry regions with fresh water [2].

Most of studies, published in the last decade, considered small capacity solar desalination systems for application in remote areas. Some of them proposed solar desalination processes used in combination with water efficient greenhouse concepts based on solar energy [3,4,5].

Thus, greenhouses combined with solar desalination systems represent an interesting possibility for the development of small scale cultivation in places where only saline water or brackish water is available [6]. The main arguments behind this combination are the following:

- Water production levels from solar desalination are not on levels corresponding to the water requirement for crops grown in open irrigated fields, but may be suitable for fresh water supply to protected cultivation [7].
- Water requirements of crops in protected cultivation have a diurnal and seasonal fluctuation which is similar to the productivity variation of solar desalination. Both

processes are primarily driven by the varying solar irradiation and therefore well correlated [8].

- Water use efficiency in protected cultivation is improved especially if it is associated with the price of vegetables. This could generate much better income for the small-scale producers, especially with limited water resources in the region [9].

The present paper is concerned with analysis of solar desalination systems that could be applied for irrigation in rural arid areas. Design and operational features of some pilot plants developed by researchers have been reported.

Despite substantial technological achievements in the recent past, the promotion of the potential for desalination using alternate energy sources is in need of major improvements. Comprehensive institutional and policy reforms are required, including the creation of knowledge basis areas. Approaches to support concrete projects will be investigated to ensure good practices and maximum benefits in the field of alternate energy/desalination technologies and to be able to identify barriers to boost the implementation of these technologies in arid areas conditions.

2. Water Resources and Agriculture

At least 80 arid and semiarid countries, where 40% of the world's people live, have serious periodic droughts [10]. Areas likely to face increased water shortage and beyond include northern Africa, parts of India, northern China, much of the Middle East, Mexico, and parts of the western United States and the central Soviet Union.

Hydrologists regard countries where local water supplies average less than 1000m³ per capita per year as water scarce. More than 230 million people living in some 26 countries, 11 in Africa and 9 in the Near East, already fall into this category. Africa, covering 29% desert and 35% arid and semiarid land [11], and Asia are already showing signs of a worsening shortage in fresh water availability, while water quality is also declining. In Contrast South America appears to be well endowed [12].

It is worth noting that agriculture occupies a prevalent place in economic activity of the arid areas region; it also occupies a prevalent place in water consumption since the majority of these countries region use nearly 80%, if not more, of their water resources for irrigation.

The limited resources of water have enforced the use of low-quality irrigation water. Recycled urban wastewater, agricultural wastewater and saline groundwater are sources of low-quality water supplied to agriculture. In many situations farmers have no alternative but to use low-quality water. In other cases, farmers have the alternatives of choosing between cheap low and more expensive good quality irrigation water and of mixing water from different sources.

Using low-quality irrigation water may reduce crop yields and damage the environment, soils, and aquifers. For instance, salts applied to soils via irrigation are either left in the soil to harm subsequent crop growth or are leached below the root zone to affect groundwater [13]. Also, there can be long-term damage to soils and aquifers that may not be easily recoverable.

Many arid areas countries facing water scarcity are low-income societies with rapidly growing populations that are generally unable to make costly investments in water management technologies. Providing water with appropriate quality becomes a greater challenge as economic development and population growth place increasing demands on limited water resources.

3. Solar Energy Potential

Solar energy is an energy source of low energy density and high intermittence. It can be easily collected in the form of low temperature thermal energy. This resource is regarded as an important resource of power energy in the future. Most places in arid areas suffering from salinity lie in high radiation zones 4 to 6 kWh/m² (annual average). This makes the use of solar desalination systems in these areas even more practical and sustainable. Here, the relatively low temperature energy required for many desalination processes makes solar energy a prime alternative for producing fresh water.

In this context, it is worth pointing out, as an example, that using solar pond plus multi effect distillation technology (MED), the expected 20% shortfall in Jordan's water needs and the 30% shortfall in Israel's needs could be provided by less than 200Km² of solar ponds using today's technology [14]. This rather optimistic forecast has two origins. First, the total energy demand to be met only by solar energy is based on the economic surface and second, the solar energy was assumed to be converted only with an efficiency of 25% that should be higher with today technology.

Moreover, given the level of dispersion of agricultural rural communities and the progressive degradation of their water resources quality, and the recent developments of alternative energy technologies, decentralized desalination based on alternative energies would be crucial to the agricultural development of these zones.

A policy for developing alternative energies for desalination would help both to improve the living conditions of people in arid areas and increase these regions energy autonomy and tackle desertification much more effectively. It is also reasonable to hope that solar energy will in a few years enable us to produce economically desalinated brackish water/sea water for irrigation purposes.

Today we are witnessing the spectacular development of techniques of exploiting solar energy power and their range of applications is constantly growing. Numerous experiments have been carried out for adapting these techniques to the socioeconomic conditions of the regions where these energies can be captured. Photovoltaic systems present definite advantages over other systems for harnessing solar power. They are particularly well suited to and regions where solar energy is enormous and can be distributed in accordance with the demand. Furthermore, since there are no mechanical pieces needed in solar panels, maintenance is easier and the equipment lasts longer. Also, the sun shines everywhere in these regions, all regions can benefit from solar energy even those that are remote and previously excluded from classical energy systems.

4. Desalination Processes for Irrigation

All over the world, including various arid zones, there have been numerous concrete successes of desalination units proving the wide range of applicability and the effectiveness of the technology for exploiting renewable energies mainly based on wind and solar power.

Despite all the advantages of alternative energy and the role it can play in the fight against desertification and agriculture land degradation, they are still not exploited to the extent that they should be. Indeed, beside economical problems they suffer from a lack of genuine and sustained attention. Also, the multiplicity of initiative and decision taking centers and resultant dispersed projects all militate against the formulation of a coherent and focused policy on alternative energy development. In many arid regions, these alternative energy sources are still regarded as mere experiments. And in the implementation of the majority of projects, only the technical aspects are considered truly important.

The main practical alternatives to using solar desalination for irrigation are discussed and performances have also been considered in the following.

4.1. Solar Still Greenhouse Combination

The complete survey of a system combining a solar still with a greenhouse was first designed by Tombe and Foex [15] and than an improved version of the concept was developed by Boutiere in 1972 and by Bettaque [16] in

1977. The concept utilized transparent pans instead of opaque ones. It consists of a double covered glass roof. The inner layer of the glass roof is covered with a shading material. Salt water flows down over this shading material between the two layers. One part of the global radiation will be absorbed at the inner liner of the roof and the salt water evaporates. The water vapor condenses at the inner surface of the outer layer, runs down along the glass and is collected by gutters for watering the plants. With the incoming light is reduced.

According to Selsuk [17], this system, though successful in operation, could not have maintained the best conditions required for the most efficient performance of the solar still and the greenhouse since plants grow most effectively under temperature and humidity conditions not favorable for the solar still productivity.

Therefore, he has proposed a solar still completely separated from the greenhouse, by placing an insulation layer under the still, to secure more effective control of the plant environment and increased yield from the solar still. Success in growing tomatoes and eggplants in this proposed design [17] could make this device used in arid rural areas without any power supplies.

The general problem arising from such designs, reported by Kudish [18] is the delicate balance between the amount of incident solar radiation absorbed by the solar still and that required by plants for photosynthesis.

Totally separation of the solar still from an unconventional greenhouse, are also recommended, after experimentation and analysis, by The Brace Research Institute. The designs presented have different shapes depending on geographic latitude [19].

From 1979 to 1984, at the University of Hanover in Germany, a closed system greenhouse with integrated solar water desalination, called the ITG- system, was developed and evaluated by Strauch and Zabeltitz [20] and compared with a modified Bettaque system.

The concept of the system, suitable for tropical desert conditions, consists of using an integration of collecting the water evaporated and transpired by condensation on the enclosure and water produced by the solar still attached to the southern side wall of the greenhouse. The modified double glazed roof still integrated still includes below the southern oriented outer glass a second glass acting as absorber and evaporator (Figure 1).

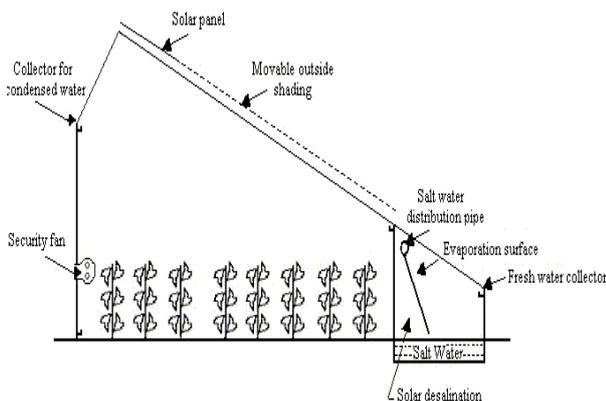


Figure 1. Cross section of the desert greenhouse designed by ITG in 1987 at the University of Adana, Turkey

Results of experiments carried out on these systems show the increase of the ITG-system efficiency compared to Bettaque system, 29% against 16%, and a productivity of 1 l/m²/day against 2-2.5 l/m²/day in ITG-system.

However, in the period between 1978-1981, Dumont and de Cachart [21] proposed in their study a greenhouse with solar distillation using a developed Bettaque concept (Figure 2).

The flow of the water for distillation as a film is maintained from a series of sprinklers located at the top of the framework. The output is very low, about 20 l per hour for each square meter of greenhouse area and consequently it needs to be steady in order to obtain uniform distribution over the whole of the greenhouse roof filters. The average daily production of fresh water has since 1978 been in the range of 2-3.5 l/m²/day in favorable conditions.

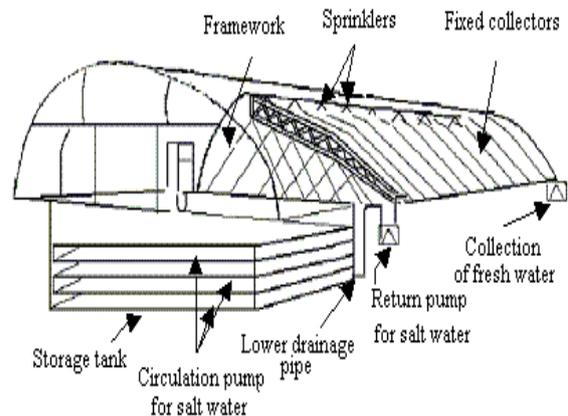


Figure 2. Greenhouse with solar desalination (M.Dumont and M. de Cachard, 1978, Grenoble, France)

From 2000-2003, Chaibi and Jilar [22] have developed at the National Research Institute of Rural Engineering, Water and Forestry an integrated solar system greenhouse based on Bettaque system. In their system, the roof light transmission is reduced as solar radiation is absorbed by a layer of flowing water on a glass covered by a top glass. Fresh water is evaporated, condensed on the top glass and collected at the roof eaves (Figure 3).

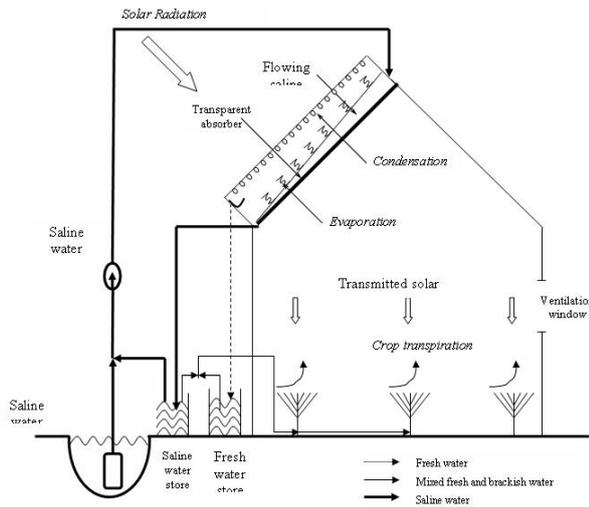


Figure 3. System principle for water desalination integrated in greenhouse roof

Their work has included the analysis of the fresh water production as well as the crop growth capacity and water demand for the concept. Also, the theoretical and experimental studies with a focus on the total system performance and design are considered. The assessment of this concept compared to conventional, single glass greenhouses includes extensive simulations and field experiments in Tunisia. Considerably less extreme climate conditions were registered in an experimental greenhouse with roof desalination compared to a conventional greenhouse. Experiments results have shown that a system integrated in 50% of the roof area of a wide span greenhouse has the capacity to cover the annual demand for a low canopy crop with a water production capacity of about 1.5 to 2 l/m², day for days with high irradiation and an exceeds of the water demand by about 2.3 and 1.6 times during the early and late period of the cultivation growing season.

Other designs have been proposed such the naturally ventilated greenhouse with built in solar still and waste heat and mass transfer, proposed by Fath [23]. This system consisted of a transparent roof with built in solar still on the top of the greenhouse roof. With this process, suitable for hot desert regions, we could decrease the greenhouse cooling load and use the surplus solar energy during the day for natural ventilation of the greenhouse and for producing fresh water varying from 1.3 to 1.8 l/m²/day.

Hassan et al. in 1989 [24] proposed a multi stage roof integrated solar still . This type has a productivity of 13.5 to 17.5 times the evapo-transpiration inside the greenhouse.

4.2. Water Production by Condensation of Humid Air

The condensation irrigation system (CI) combines desalination with irrigation by humidifying ambient air with brackish/or sea water heated by solar energy and dehumidifying it in a drainage pipes buried in the ground. The humidification/dehumidification process might be the answer for the optimum choice of a small scale

desalination unit. The process requires a low level of technical support when compared to other process.

Condensed water and humid air infiltrate the soil through the pipe perforation and irrigate and aerate the soil. This irrigation method increased the irrigation efficiency and eliminates water loss through surface runoff. Furthermore, when using solar driven air humidification, water production is more effective during warm and sunny days when the irrigation need is high.

Previous studies of condensation irrigation (CI) have been carried by many researchers. Widegren (1986) [25] performed theoretical studies on a CI system that irrigated a land area of 1ha by using a fun power. Nordel (1987) has constructed a small scale plant in a greenhouse for cucumbers in Overtornea, Sweden [26]. Ruess and Federer constructed a CI plant where seawater was evaporated in plastic tubes and condensation occurred in buried drainage pipes [27]. A reported 50% reduction in the water consumption of tomato plants was observed in the system. Gustafsson and Lindblom (1999) carried out theoretical and experimental studies on CI in Turkey [28]. The theoretical analysis, developed by Lindblom, indicated that the CI is a promising alternative irrigation method as it enables the use of saline water in irrigation.

The Tunisian National Institute for Research on Rural Engineering, Water and Forestry (I.N.R.G.R.E.F) constructed in 2004 a pilot plant for condensation irrigation at the Chatt Meriam situated at the costal part of Tunisia. This region is characterized by climate variability and a minimal rainfall. A schematic of the experimental system is shown in Figure 4. This plant includes three main parts: storage basin, solar panels and a ventilator, inducing the air humidification (evaporation) and the air dehumidification (condensation) processes.

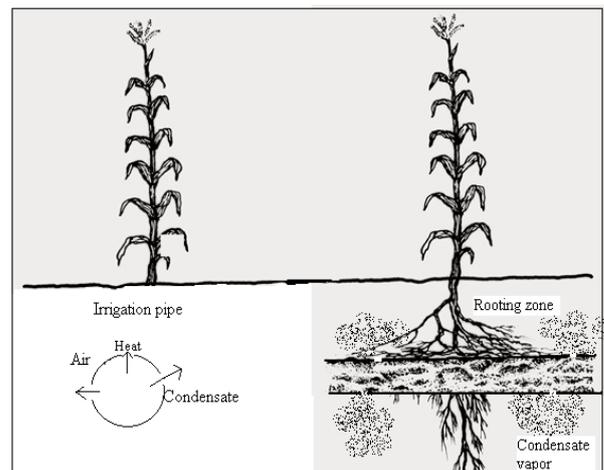


Figure 4. Section of the drainage pipes buried in the field

(i) Air humidification (evaporation) water is heated by solar collectors in a closed loop system. The induced airflow by a ventilator is warmed at first phase through the piped submerged inside the storage basin and then conducted to the drainage pipes for sub-surface irrigation.

(ii) Air dehumidification (Condensation)

The warmed humidified air releases its heat in the ground at the drainage pipes level, gradually reducing the cooling capacity of the system and generating the fresh

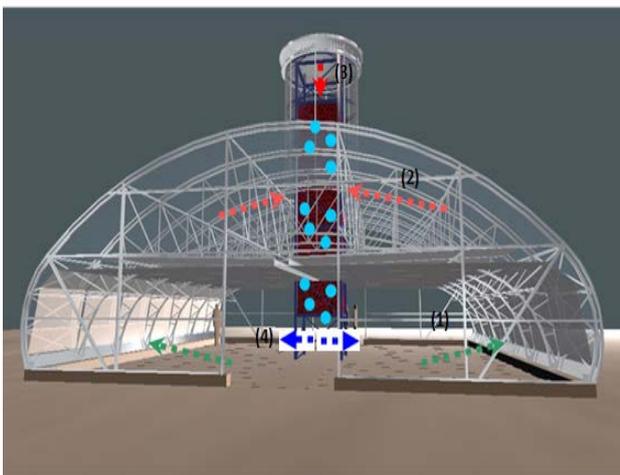
water production in the soil. These pipe perforations enable air and water to infiltrate the surrounding soil and thereby irrigating the crop directly in the rooting zone.

According to experiments performed in the pilot project of Chatt Meriam in Tunisia, irrigation by underground condensation of humid air could offer a quantity water production able to satisfy more than halved the crop water needs for chosen crops practiced in arid region of Tunisia (Table 1). According to the simulations developed by Lindblom and Nordell [29], this water production could be doubled when the inlet water temperature would increase by 20%.

Table 1. Coverage degree (production/demand) for the irrigation by humid air condensation

Daily water production (mm/day)	Rate of satisfaction in water needs (production/demand) (%)				
	Green beans	Peas	Tomato	Potatoes	Onion
2.8	51 - 56	69 - 71	57 - 64	61 - 68	74 - 81

In 2007, Zaragoza et al. [30] proposed a new concept for a single closed greenhouse for advanced horticulture use, which acts as a climatisation system and as a process for grey or saline water desalination. It consists of a greenhouse with a solar chimney, inside which a cooling duct contains an air-to-water heat exchanger connected to a heat accumulator. The process starts with the heating, by evapotranspiration of the plants and the soil, of the humidified air inside the greenhouse, which then rises up inside the solar tower by natural buoyancy. This rising air becomes saturated via evaporation of saline water from a pan placed on the top of the planted area. On the surface of the heat exchanger, cooling of the saturated humid air creates condensation, thus releasing additional thermal energy and distilled water (Figure 5). The first prototype of this concept was built in Almeria, Spain. The testing phase of the concept is on-going and technical improvements and research will present further challenges.



(1) Humid air from greenhouse through evapo-transpiration process; (2) Ascension of heated air to the tower –through secondary collector; (3) Cooled air to fall back to the greenhouse through condensation on heat exchanger; (4) Irrigation to plants

Figure 5. Scheme of a novel solar humid-air-collector system for greenhouse horticulture (after Zaragoza et al, 2007)

4.3. Conventional Greenhouses Assisted by Solar Desalination Plants

The irrigation projects for protected cultivation drawing their water from solar powered desalination plants has not gone yet beyond the experimental phase and pilot projects. In this section, two pilot projects localized in the south of Tunisia will be described.

4.3.1. Solar Desalination Plant with Single Effect Process Using Heat Pipes Collectors

This plant constitutes a joint research effort to gain actual field experience for greenhouse irrigation [31]. The plant is composed of three parts (Figure 6).

The collector of 80 m² is composed of three ranges of heat pipes. Each range links 12 heat pipes panels. Brackish water pumped from the well is filtered and passed through a heat exchanger where it is heated by the distilled water which circulates into the heat pipes.

The evaporator: the salt water leaves the heat exchanger at about 60°C and is directed to the top of the evaporator where it is discharged into a porous media of polyethylene balls. During its flow, a part of salt water is evaporated and the other part is recuperated at the bottom to be stored or used for greenhouse heating.

The condenser: the vapor reaching the top of the evaporator is then exhausted at the bottom of the condenser formed by the tank filled with the polyethylene balls to increase heat exchange. During its forced rising from the bottom to the top of the condenser, a part of the vapor is mixed with a fresh water sprayed at the top of the condenser to be cooled for its condensation. Distilled water is then pumped through the heat pipes and the heat exchanger part of it is sprayed again at the top and the remainder is stored.

The fresh water produced by this process is limited to an amount of 5- 6 l/m², day. This production constitutes almost half the quantity of fresh water intended to be produced by this plant. The release of fresh water produced have met effectively the crops water needs for two plastic greenhouses with an area of 1200m².

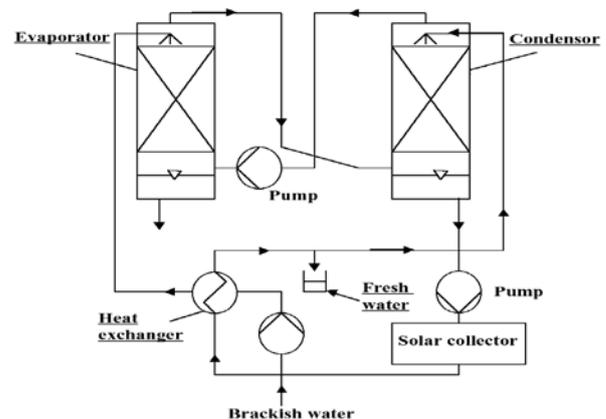


Figure 6. System principle for solar desalination plant using heat pipes collectors

4.3.2. Solar Multiple Condensation Evaporation Cycle Process

The second desalination process is a technology with promising diffusion and application due to its flexibility, design, construction and adaptation for use in rural areas to produce fresh water for drinking and irrigation [32].

The system operates at atmospheric pressure in which air is used as a carrier for vapor. Figure 7 displays a pilot unit which has three major components: solar collectors, evaporation tower and condensation tower.

First, brackish water is heated by the flat plate solar collectors having an area of 56m². The warm water is injected in the top of the evaporation tower equipped with a packed bed thorn trees to increase the contact surface and improve the humidification rate. Warm and saturated air mixes with rising air current toward the condensation tower by natural or forced convection. The humid air condenses in contact with the cold condensation plates.

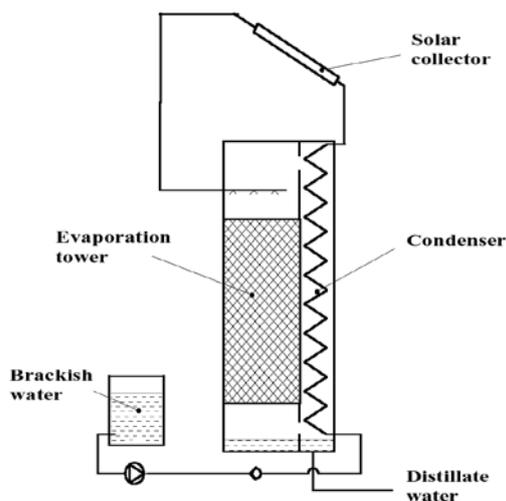


Figure 7. Solar multiple condensation evaporation cycle process with flat plate solar collectors

Brackish water is preheated in the condenser due to heat exchange with fresh water vapor to be condensed. This will reduce the thermal energy consumption needed for water heating in the solar collectors. The distilled water is collected in a basin at the bottom of the condensation tower. Water which may not be evaporated is collected in a basin at the bottom of the evaporation tower and is recycled or discarded in case the salt rate is too high (Figure 7).

The desalination unit production has exceeded 4.5 l/m², day of fresh water during days with high irradiation levels [32]. The distilled water is then mixed with saline well water for irrigation use in plastic greenhouse.

5. Strategies for Introducing Desalination Technology for Irrigation

Many countries in arid regions need to reconsider their agricultural strategy regarding desalination use for irrigation. This means that current cropping has to be changed, new crops should be introduced and new technologies should be adopted that will improve the crop productivity per unit of land, decrease losses, improve the

quality, and increase the return per unit of land, labor and water.

Water desalination using renewable energies is considered a promising technology to be adopted by small scale farmers in protected cultivation. This technology has not been enough investigated and analyzed to be incorporated in the global scale of irrigation water policy as priority is going towards water catchments management and water conservation measures. Nonetheless, desalination for irrigation is being increasingly seen as viable water supply option and becoming, in the near future, increasingly cost competitive.

The main questions about irrigation water supply in rural irrigation communities relate less to its usefulness than to financing and costs and whether alternatives are more cost effective. Let us consider these questions in turn.

5.1. Financing and Lowering the First Cost of Desalination System Based on Renewable Energies

As with other forms of water desalination plants, the initial costs of implementing this system equipment for irrigation, constitutes a significant barrier to the widespread adoption of the renewable energy sources for water desalination. The development of innovative financial schemes, including supplier credits, leasing arrangement and micro-financing arrangement, is thus a critical element of any renewable energy program. Incentives in support of the development of local energy companies those themselves may be willing to finance the initial costs or extent credit. In recognition of their positive externalities of innovation and their environmental advantages, countries legislation have to exempt renewable energy technologies from at least substantially lowering taxes and duties, while at the same time taxing conventional energy industries supplies in accordance with standard principles of tax policy.

5.2. Encouraging a Diversity of Investments and Investors

In water scarce countries, the desalination system for irrigation should receive the attention it warrants, it should be recognized under the national water initiative. International donor community should support and encourage investment and policies in this field through a large program. This one should provide information on project experience, technical advice, and cross support and encouragement to the regional operating division to prepare these projects and policies for financing.

5.3. Create Knowledge Basis

It is normal way for raising countries the anxiety to develop their people through the introduction of new technologies such those applied for water desalination for irrigation purposes. The dichotomy existing between the desalination technologies and the local mentality has been, since the introduction of the first plants, cause of several troubles for the local responsibilities.

As we expect that the increase of the desalination plants in the arid region over the next decades, it is apparent that there will continue to be an associated increasing worldwide demand for personnel trained in both the theory and practice of desalination.

In order to allow such turn-over, the following aspects given below should be considered.

- Existing Research and Development Institutes: The primary goal of such institutes dealing with the desalination R&D program is to develop more cost-effective and technologically efficient means to desalinate irrigation water.

- Research and Development at regional & international level: At regional and international level, it is recommended the establishment of research and developments centers assigned the following functions:

- (i) To carry out the needed research and development energy needs;

- (ii) To field-test and provide feedback from users to improve renewable energy processes and evolve useful desalination concepts for irrigation purposes.

- (ii) To act as information, education, and training center with local universities; and;

- (iv) To maintain close contact with scientific and engine and renewable energy applications in other centers and in industrialized countries.

These centers could help target countries to introduce and identify current or new technologies relevant to desalination systems concepts. Staffed by experts drawn from government, industry, farmers and academic circles in both industrialized and developing country, it could provide training for local and regional technicians or specialists in energy and water problems. It could become a central point of contact where policymakers and experts could exchange ideas on plans and programs. Further, the institute could become the first bridge between the massive efforts of the industrialized countries that launched to develop alternative sources of energy for desalination, and the effort which the target countries interested in undertaking desalination systems technologies.

The work of these regional institutes should be directed toward lowering the cost of desalination technologies, so that they become financially accessible mainly to small farmers in developing countries, and using local material and manufacturing capabilities whenever possible.

Transfer of information and technology

This transfer of information and technology should give greater emphasis to the exchange between regions of a similar type with a common requirement, rather than attempts to transfer, possibly inappropriate, technologies from other regions where they have been developed to satisfy different requirements. All the well tried methods of such exchange should be utilized, but in particular, regional meetings, such as symposia, seminars and workshops should be encouraged. The possibility of regional information centers for utilization techniques should be investigated. Co-ordination within regions, as well as between regions, is very desirable, as is the encouragement of relevant regional research projects.

In connection with training matters, we should emphasize the great importance of the development of

education, mainly at university level, in desalination technology and utilization. Although the achievements in the domain of technology cannot always be exported readily from one region to another, relevant aspects could be adapted to the special needs and possibilities of the other regions. These are regions which need help to develop their own technology in the field of renewable energies desalination use. It is generally believed every renewable energies desalination concept has to be uniquely designed within the context of the physical, social and financial parameters they intend to serve. As a result, what may be assessed economical or practical in one location may not be applicable in another.

For this purpose, education and training activities should be improved. These should be combined with a demonstration of the physical and practical possibilities of using renewable energy as well as with a clear indication of the value and efficiency from the points of view of economy of energy, water chemistry, plant selection for given environmental parameters and constraints, materials for desalination and power plants, and analytical techniques of desalination.

There will thus be a continuing need for professional training which we believe is probably best provided through postgraduate training of engineers and scientists, ideally, but not essentially, together with the experience in plant operation or some other aspect of desalting practice.

The education and training should be made on a multi-disciplinary basis. The exchange of information between scientists and research workers should be extended and organized, but it should be, above all, completed by a wider activity at various levels and especially for practical education of engineers and technicians for installation, running and maintenance of desalination plants. At the various levels it has been pointed out, that a broad based and well founded basic knowledge should be preferred to great specialization in one particular aspect in the field.

Education exchange should be arranged through the formation in every region of groups of people keeping contact together to ensure better development of the education and training activities. The existing lack of educational materials should be overcome by the preparation of appropriate booklets, manuals, text books and courses, which should be made available to people in charge of education.

6. Conclusion

There is a growing need to find solutions to the problems of fresh water supply for irrigation purposes. This need is amplified in arid and coastal agricultural communities. In these locations, not only are fresh water resources limited but the local small farmers are also outside any potential reasonable cost water and energy delivery infrastructure. In such a context, it is clear that decentralized desalination systems for irrigation are crucial to the development of these zones. The development of these systems has not advanced much beyond demonstration status.

The general and main conclusions which can be drawn from experiments results on some practices alternatives to

using solar desalination for irrigation in arid areas conditions are the following:

A greenhouse with integrated water desalination could be designed to provide technically feasible systems suitable for arid climate conditions. It provides the optimum environment temperature with minimum fluctuation, which is desirable from thermal load leveling point of view. Greenhouses with full coverage of the irrigation water demand are possible to design with the concept. This is provided the use of mixed fresh water and brackish water from ground water sources with limited salinity.

According to experiments performed in the field, irrigation with humid air in subsurface drainage pipes could supply more than halved crop needs in open irrigation areas. Assuming this result to be valid, crops in protected cultivation could be satisfied totally using the condensation irrigation concept.

The greenhouse integrated system and the condensation irrigation is found to be a reliable and valid technologies with low investment and water cost compared to solar collector based desalination technologies.

The different designs and concepts of an integrated greenhouse solar still presented above constitute an exciting option for the support of small scale agricultural production, in places where only saline water is available, and especially when it is applied to high-value crop cultivation, such as vegetables and flowers grown in greenhouses.

In order to significantly increase the share of alternative energy in irrigation water needs and implementing strategies to fight droughts and desertification, it is essential to fundamentally re-think the energy and water policies in most of the countries severely stricken by aridification and desertification.

In more general terms the future research about water desalination with the actual concepts should be more focused on advanced and combined concepts for several purposes useful for human consumption.

Taking the above into account, it is clear that cooperation between arid and semi-arid countries in Africa and the developed world in the energy domain, and particularly with respect to renewable energies desalination technologies, offers huge opportunities for Africa to develop more rational energy policies. Up to now that cooperation has not been adequately explored and/or sought after.

References

- [1] Ad hoc panel on promising technologies for arid land water development, *More water for arid lands*, National Academy of Sciences- National research council, Washington, 1973, 73-135.
- [2] Gischler, C.E, *Water resources in the Arab Middle East and North Africa*, ENAS Middle East & North African studies Press Ltd., 1979.
- [3] Tinaut, D., Echaniz, G. and Ramos, F., "Materials for a solar still greenhouse". *Optica Pura Applicada*, 11, 59-61, 1978.
- [4] Sodha, M.S., Kumar, A., Srivastava, A. and Tiwari, G.N., "Thermal performance of solar still on roof system," *Energy Conversion and management*, 20 (3), 181-190, 1980.
- [5] Luft, W. and Froechtenigt, J., "Solar energy controlled environment agriculture in the United States and Saudi Arabia". SERI/TP-270- 1465 1981.
- [6] Malik, M.A.S., Tiwari, G.N., Kumar, A. and Sodha, M.S., *Solar distillation: A practical study of a wide range of stills and their optimum design, construction and performance*, First edition. Pergamon press Ltd. Oxford, England, 100-109, 1996,
- [7] Kudish, A.I. and Gale, J., "Solar desalination in conjunction with controlled environmental agriculture in arid zones," *Energy Conversion and Management*, 26 (2), 201-207, 1986
- [8] Tiwari, G.N., Sinha, S., Saxena, P. and Kumar, S. "Review of solar distiller in other thermal applications" *International Journal Solar Energy*, 13, 135-144, 1992.
- [9] Abou Hadid, A., Batanouny K.H., Jabarine, A.S. and Kader A.A. *Proposal for expanding the crop mandate of ICARDA to include horticultural crops.*, Report ICARDA 07/250/ April, 2004.
- [10] Tyler Miller.G, Jr., *Environmental science*, Third edition Wadsworth publishing company Belmont, California, A division of wadsworth, Inc., Chap 11, 236-239, 1991.
- [11] Horchani, A., "Shortage of water: a fundamental problem in arid and semi-arid areas," *Proceedings water resources in the next century, Stockholm water symposium*, 31-36, 1991.
- [12] Wolter, H.W and Kandiah, A., "Harnessing water to feed a hungry world", *16th congress on irrigation and drainage*, volume 1H, 2-22, 1996.
- [13] Tanji, K.K. and Enos, C.A.. *Global Water Resources and Agricultural Use. In: Management of Water Use in Agriculture*, Eds:K.K. Tanji and B. Yaron, Springer-Verlag, Heidelberg, Germany, Chapter 1, 3-24. 1994.
- [14] Tabor, H., "Solar desalination: a technology for peace" *Sun World*, .21: 20-22, 1997.
- [15] Trombe, F. and Foex, M., "Utilisation of solar still energy for simultaneous distillation of brackish water and air conditioning of hot houses in arid regions" *U.N. Conf. On new sources of energy*, Paper 35/S/64 Revised, Rome: 11p. 1961.
- [16] Bettaque, R.,Vefahren "zum Betreiben von Gewachshausern mit salzwasser" *Der Tropenlandwirt*, Beiheft 10, Witzenhauser Hochschulwoche, 1977.
- [17] Selsuk, M.K. and Tran,V.V., "Solar stills for agriculture purposes.," *Solar energy.*, 17. 103-109, 1975.
- [18] Kudish, A.I., *Water desalination; Solar energy in Agriculture*, B.F.parker. Elsevier Science Publishers B.V., Netherlands., 1991.
- [19] Selsuk, M.K. and Tran,V.V, " An overview of solar still greenhouse performance and optimal design studies", *Conf. on heliothermique and development*, 2, 349, 1975.
- [20] Strauch, K.H., "A closed system greenhouse with integrated solar desalination for arid regions" *Acta Horticulturae*, 170, 29-36, 1985.
- [21] Dument, M. and de Cachard, M., "A greenhouse with solar distillation" *Plasticulture*, 61. 11-24, 1984.
- [22] Chaibi, M.T. and T. Jilar.T., "System design, operation and performance of roof integrated desalination in greenhouses" *Solar Energy Journal*, 76 (5), 545-561, 2004.
- [23] Fatih, H.E.S., "Transient analysis of naturally ventilated greenhouse with built-in solar still and waste heat and mass recovery system," *Energy conservation and management*, .35(11). 955-965. 1994.
- [24] Hassan, M.S., Toyoma,S., Murase,K. and Wahhab, M.A., "Multi-effect solar still for agricultural purposes in hot climate" *Desalination*, 71. 347-353. 1989.
- [25] Widegren, M. "Condensation irrigation, desalination irrigation system", Master thesis 1986:002E, Lulea University of technology, Sweden. 1986.
- [26] Nordell, B., "Design of climate system for greenhouse in the north of Sweden", Report Lulea University of Technology, Sweden. 1987.
- [27] Ruess, K. and Federer, H., "Using sea water for irrigation" *The Agricultural Engineer*, 45 (4). 116-117. 1990.
- [28] Gustafsson, AM. and Lindblom, J. "Underground condensation of humid air – a solar driven system for irrigation and drinking water production", Master thesis 2001: 140 CIV. Lulea University of Technology, Sweden, 2001.
- [29] Nordell, B. and Lindblom, J., "water production by underground condensation of humid air", *Desalination Journal*, 189. 248-260. 2006.

- [30] Zaragoza G, Buchholz M, Jochum P, Pérez-Parra J “*Watergy project: towards a rational use of water in greenhouse agriculture and sustainable architecture*,” *Desalination* ,211. 296-303, 2007.
- [31] Chaïbi, M.T., Saffi, M.J. and Hsairi, M., “*Performance analysis of solar desalting unit in south Tunisia*”, *Desalination Journal*, 82. 197-205. 1991.
- [32] Ben Bacha, A.Y., Maalej, A.F., Ben Dhia, H.,Ulber, I., Uchtmann, H., Engelhardt, M. and Krelle, J., “*Perspectives of solar powered desalination with “SMCEC” technique*,” *Desalination Journal*, 122. 177-183. 1988.