Solar Distillation

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solar distillation

In remote, arid regions of the world, the lack of a safe and reliable drinking water supply is one of the fundamental constraints to securing the population's subsistence. Solar distillation is one of the technical options that can provide a reliable supply of water to cover basic demand.

Solar distillation competes with conventional fuel-operated plants as well as water transports.

This competitive situation has posed an obstacle to the dissemination of solar stills on a broader scale to date. Only in exceptional cases are the real costs, much less the often subsidised costs, of transporting water higher than the costs of supplying water with solar-powered plants - which amount to roughly DM 50 per cubic metre. Even conventional fuel-driven plants can produce water more cheaply than solar stills at capacities of just a few cubic metres per day.

The need for regular maintenance and repair poses another obstacle, especially in the case of publicly operated plants.

For these reasons, the application of solar stills is limited to small-scale systems that supply less than 3 cubic metres per day, primarily for private operators in remote areas where water-supply costs exceed DM 40 per cubic metre. In these scenarios, solar stills represent an attractive and competitive option.

In addition to their use in obtaining drinking water, solar stills are also suitable for the production of distilled water if there is an appreciable demand for it in industry, laboratories, medical facilities or to fill lead-acid storage batteries.

Key data on solar stills

Distillate yield: 2-3 litres/sq.m/day
Investment costs: DM 200-600 /sq.m.
Capacity Range: up to approx.2 cubic metres/day
water costs: approx. DM 50/cubic metre

In a few dry and remote areas of the globe, drinking water is extremely scarce. The available wells supply only brackish water which is unpotable or contaminated. Clean drinking water must be hauled over long distances, resulting in high costs and frequent supply shortages.

In order to improve their supply of drinking water, the people who live in these areas need a desalination technology that is simple, reliable and economical. It should be a technology that can be installed and operated by local personnel with the appropriate training and it should not lead to any additional dependence on fossil fuels.

Solar stills can meet these requirements provided certain prerequisites are given. Although the utilization of solar energy does not entail any operating costs, solar-distilled water is more expensive than water from large-scale, conventional desalination plants due to the high investment costs. The following prerequisites are critical for the economic viability of solar desalination and severely limit the range of application:

- lack of (adequate) local sources of drinking water
- availability of saline or brackish water in sufficient quantities
- demand for water lower than 3 cubic metres per day
- high fuel costs and/or unreliable supply
- water transport costs higher than DM 40 per cubic metre
- less than 400 mm annual rainfall
- good solar radiation conditions with no significant seasonal fluctuations

Based on current price levels, the costs of solar-distilled water lie in the range of at least DM 40 per cubic metre. The cost of water supplied by conventional plants (with significantly higher capacities), on the other hand, comes to DM 5-20 per cubic metre. Even if the benefit of more reliable supply is taken into account, the operation of a solar still is only economical if the quantities of water produced are not very high.

Solar desalinators are primarily employed for drinking water supply. Generally speaking, irrigation projects, and even livestock-raising operations, are not profitable enough to cover the high costs of water production for these applications.

Solar desalination of seawater in coastal sites is also limited to isolated cases, since is it usually less costly to supply drinking water by ships.

The economics of producing distilled water strongly depend on the local market conditions. Particularly in cases where the level of demand is low, solar stills can provide an independent supply of water with a simple technology and thus have certain advantages over other procurement options.

Solar desalination technologies

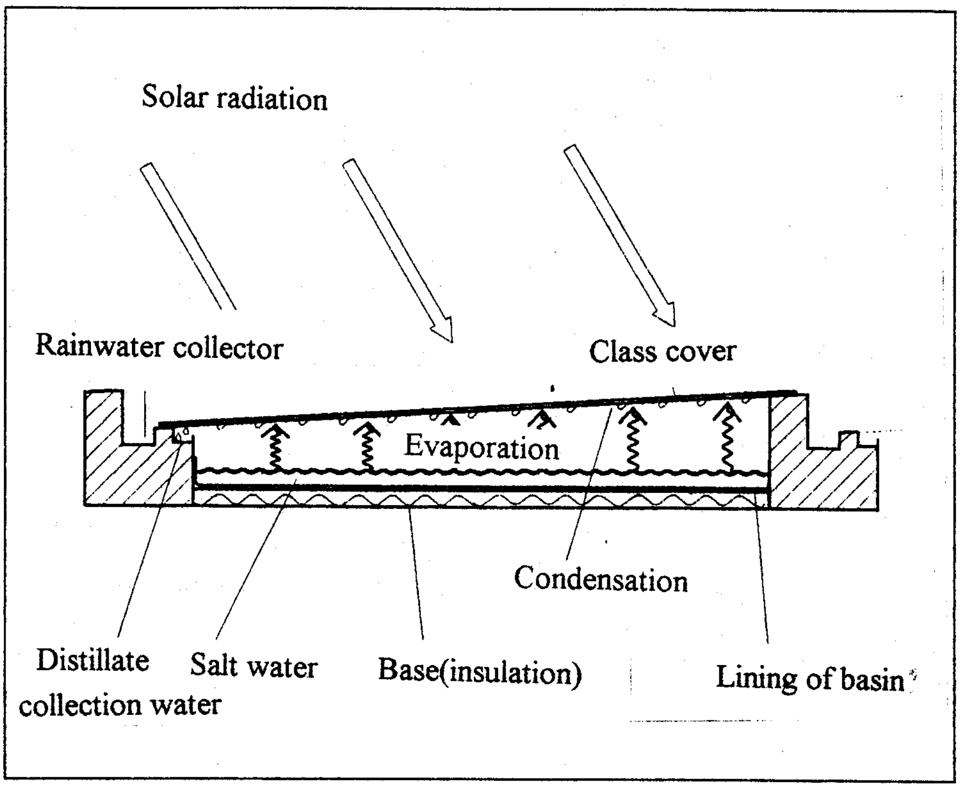
Although many different solar desalination methods have been developed and field-tested in recent decades, only the simple basin-type stills have actually been employed in practical applications on any appreciable scale.

The solar still consists of a basin that is coated with a black lining to absorb the solar radiation. The basin to hold the salt water is covered with an airtight roof made of glass or plastic sheet. The solar radiation passes through the transparent cover and is absorbed by the dark surface at the bottom, which heats up the water in the basin and delivers the energy for the evaporation process on the water surface. Some loss of heat occurs at the cover through reflection and absorption, at the bottom and sides of the basis through conduction and also through radiation.

The air inside the still is now completely saturated with vapour. It is heated on the surface of the water, where additional vapour is produced through evaporation. The warm, moist air then rises by convection to the cooler cover, causing some of the vapour to condense in the process. The condensate runs down like a film along the underside of the cover and is channeled through a gutter to the fresh-water tank.

The energy flows between the surface of the water and the cover result from the evaporation energy of the still (utilization energy) and the radiant heat being transported by the moist air (loss energy). Both forms of energy are given off at the cover and lost as a result. Progressive still designs with thermal recovery features make multiple use of this energy and can thus raise the efficiency roughly tenfold.

The minimum amount of energy required for the simple evaporation process is approximately 700 kWh per cubic metre. Given this value, basin stills achieve average efficiencies of about 30%. In other words, at radiation of 5 kWh per square metre/day, a still will yield 2.5 litres of distillate per square metre and day.



The amount of distillate produced is strongly influenced by the surrounding conditions. The higher the ambient temperature, the higher the efficiency. If at all possible, the site of a still should be shielded from the wind.

Construction of basin stills

The economic viability of a solar still is determined to a critical degree by the construction and the materials employed. A compromise must be made between several conflicting objectives:

- low investment costs
- long life
- low operating and maintenance costs
- high degree of efficiency.

Basin stills can be produced with locally available materials and processing techniques. This lowers the costs and simplifies the maintenance and repair work.

When constructing a still, it is important to work with a design that makes sense from a technical standpoint and is properly executed. This will minimize the risk of low capacity utilization and high failure rates, which have an adverse effect on the technology's acceptance and economics.

Cover

The cover must exhibit good light-transmitting qualities, be weather-resistant and not leak vapour. Tempered low-iron glass is the best choice of material for the cover, since it is highly transparent and much less susceptible to breakage than other materials. However, simple window glass of the type used in greenhouses is a good alternative owing to its favourable price. The dimensions of the still should correspond to the standard, low-cost sizes in which materials are normally available.

Although plastic sheet is much cheaper than glass, it poses considerable problems with regard to durability. In addition to ultraviolet radiation and strong winds, animals may also do serious damage to the cover. In the case of one Greek design, for example, birds picked on the underside of the foil for drops of water and cats sitting on the warm stills in the evenings punctured the foils with their claws, leading to the failure of this model.

The efficiency of a basin-type still increases the smaller the distance between the cover and the surface of the water. For this reason, it is advisable to have a low-lying construction with a cover tilted as low as possible. If the slope is too low, however, some of the water droplets may fall back into the basin. This is why many publications recommend that the slope be no lower than 10o. However, as Gordes and McCracken (1) have pointed out, window glass is covered with a thin oily film when it comes from the factory; if it is cleaned with a suitable detergent, the water will supposedly form filmwise condensation on the glass and run off at a slope as low as 1o. Plastic covers must be tilted at a substantially higher angle than glass because the condensate is much more likely to drip rather than run off.

Because the radiation strikes the off-side of the still at a very low angle, much of the energy is lost through reflection. Therefore, stills with covers sloped to only one side exhibit more favourable conditions. In these models, the other side of the still consists of an insulated, reflecting wall to which the hatch for filling and cleaning purposes is also attached. A significant improvement in output has been achieved with this design, especially at higher latitudes.

Basin and lining

The basin must be able to withstand the aggressive corrosion conditions in warm salt water and readily absorb the solar radiation. A smooth surface makes it easier to remove deposits.

Concrete basins lined with tarpaper, butyl rubber or bituminous paint are a low-cost and proven method. Basins made of plastic or coated aluminium are a more expensive, but also more durable, alternative. Moreover, an insulated base helps to improve the still's efficiency.

The water level in the basin should be kept as low as possible so that the still will heat up quickly to a high temperature and efficiency will be improved. However, this also calls for closer monitoring of the water level in order to prevent deposits.

Insulation

Insulation along the bottom and sides of the basin will improve the still's output of distillate by up to 15%. It is only worthwhile if the additional costs incurred are no higher than that. Styrofoam or polyurethane foam can be employed as insulating material.

If possible, stills that are not insulated should be built on dry, sandy ground, which is less heat-conductive.

Other system components

In addition to the actual stills, tanks to hold the salt water and the distillate, fixtures, tubing and a fence to guard against theft and glass breakage by animals or children at play are also required. Moreover, tools, spare parts and material for maintenance and repair work must also be available.

Polyethylene piping and fixtures are well-suited to withstand the prevailing climatic conditions (high temperature and ultraviolet radiation). Otherwise, only stainless steel can be employed for parts that come in contact with salt water.

Rainwater collection

Solar stills are ideal for collecting rainwater. If annual rainfall is 250 mm or higher, it is worth the low additional expense that is required to incorporate this feature in their construction.

In areas with over 400 mm of rainfall, it is cheaper to utilize the solar still exclusively for collecting and storing rainwater. Information on the construction of catchment surfaces and cisterns can be found in the GATE brochure "Rainwater Reservoirs; Above Ground Structures for Roof Catchment".

Use of the distillate

For all practical purposes, the distilled water from the still is pure and free of dissolved salts. Thus, it can also be used as water for lead-acid storage batteries, in laboratories or for medical purposes. A salt content of 100 to 1000 mg/l is recommended for drinking water. Consequently, an appropriate amount of saline water must be added to the distillate in order to prevent a disturbance of electrolyte levels. Depending on the salt content, the quantity of drinking water will be up to 30% higher than the amount of distilled water.

Plastic still components release substances into the water that can give the distillate a bad taste. Water from stills with fibreglass basins may be unpalatable for years. Therefore, the use of this material is not recommended.

Service and maintenance

The servicing and maintenance of solar stills does not require any special know-how and can be handled by personnel who are easy to train. However, these tasks are relatively labour-intensive and can grow monotonous in the case of very large (several 1,000 sq.m.) plants. The most important tasks that need to be carried out are:

- daily filling and emptying of the stills
- collection of the distillate, admixture of raw water and distribution to users
- cleaning of covers and basin lining
- inspecting and repairing of valves and sealants
- replacement of broken glass
- removal of deposits and crust or, if necessary, renewing/touching up the coat of paint or lining applied to the basin

Costs of solar stills

The cost data for solar stills vary widely, depending on the mode of construction and the kind of materials employed. System costs in the range of DM 200 to 600 per square metre seem realistic. Annual output amounts to about 1,000 litres per square metre. Given a 10% rate of interest plus principal, the price of one cubic metre of distillate would be DM 40 based on the capital costs alone, not including the costs of operation and maintenance.

Socio-economic impact of solar stills

The investment costs of solar stills are so high that they are generally not affordable for poor population groups themselves. A plant supplying a family with no more than a few litres of water per person and day may well be more expensive than the house in which the family lives. For this reason, the financing for such installations can only be provided by the government, which, after all, is also usually responsible for drilling boreholes or supplying water by truck.

In view of the low and seasonally fluctuating output, solar stills are not designed to cover total demand. They are only equipped to supply the demand for water that is necessary for survival, i.e. for drinking and cooking. Brackish water can be used for bathing and clothes-washing if the salt content is not too high. Salt water can be used for livestock-watering if the salt content is no higher than 10g/l (for cattle) or 15 g/l (for sheep). Solar stills are not an economical water-supply option for larger-scale livestock operations.

It is still necessary to supplement the supply of water from solar plants with transports of water by truck. Nonetheless, a supply option that covers the basic needs for water considerably improves the living conditions of a population since it counteracts the risk of acute water shortages when water trucks are delayed. It provides a village community with a safe and reliable supply of drinking water and makes it less dependent on government services.

Operation and maintenance of the plant require regular daily inputs of labour. This requirement can best be met if the users of the plant are responsible for doing this themselves. One or more plant operators have to be trained and remunerated for this job.

The economic viability of solar stills is primarily determined by the costs of alternative water supply options. In Botswana, a payback period of about 2.5 years was calculated for a site-to-source distance of 60 km for drinking water. The estimated lifetime ranges between 10 and 20 years, depending on the construction. However, this presupposes regular maintenance and repairs - more specifically, plugging leaks, replacing broken glass, cleaning off crust and, if necessary, touching up or applying a new coat of paint or glaze to the basin. If these tasks are neglected, the plants may become useless after only 2-to-4 years.

Dissemination of solar stills

The first large solar distillation plant was built in Las Salinas, Chile as early as 1872. Even by modern standards, this plant, which is 4,460 square metres in size and produces 22.7 cubic litres per day, is one of the largest ever built. From a technological standpoint as well, the wood and glass construction is, for all practical purposes, no different from the models being built today.

In the 1960s and 1970s, a few relatively large stills were built in Australia, Spain, Tunisia, on the Aegean islands and in several other countries. However, many of them are no longer in operation since it is cheaper to transport drinking water to the plant locations than it is to run the stills.

More recent activities have been undertaken to disseminate solar stills in Botswana, for example, where solar stills were used to supply water to several small, isolated settlements in desert areas during the 1980s. In the Republic of Niger, small, transportable stills were developed to obtain distilled water for automotive batteries and pharmaceutical purposes.

Approximately 5,000 solar stills are currently in operation in India, where they are used either to supply drinking water or to produce distilled water for other applications [7].

Improved solar desalination methods

A large number of improved models and other distilling methods have been developed in order to increase the low yield of solar stills.

The simplest approaches are aimed at achieving evaporation on a tilted surface in order to improve the still output when the sun is low in the sky.

This can be achieved by arranging several basins in a terraced configuration (multiple tray tilted stills) or optimising the evaporation process on a piece of cloth saturated with water (tilted wick stills). Although the output of distillate with these designs is up to 50% higher than that of other solar stills, they have failed to gain widespread acceptance because their construction and operation in particular are much more costly and labour-intensive. It is relatively difficult to remove crust and deposits, the major drawback involved in the operational maintenance of these stills.

More sophisticated plant designs separate the distillation process from the solar collector. The output of distilled water can be doubled or increased eight-fold by recovering the condensation heat. Research in this area is currently focusing on the multiple-effect distillation and trans-membrane-distillation techniques. However, because such plants are much more complicated to construct and require a significant amount of auxiliary energy, they have not been found to operate any more cost-efficiently than simple basin stills. Moreover, considering the area of application in which they would be used, they are not as suitable due to their technological complexity.

The same holds true to an even greater degree of plants based on the Multiple Stage Flash (MSF) principle that are run on solar energy instead of fossil fuels. The need to adapt such plants to the intermittent and fluctuating supply of solar energy poses major technological problems that have not been solved satisfactorily to date. At best, solar energy can be used to save fuel in the operation of fossil-fired plants. Even in such cases, however, the savings will only amount to 30% at most. It is not likely that such plants will become economically competitive in the foreseeable future.

Other desalination methods

MSF Plants

Most large conventional desalination plants function according to the Multiple Stage Flash principle. A large number of stages result in a high thermal recovery factor, which makes it possible to cut the consumption of fossil fuel down to about 5% of the energy required for a simple one-stage distillation process. Since this efficiency factor can only be achieved with a large number of stages and large thermal exchange surfaces, the construction costs of MSF plants are very high. Energy can also be used more efficiently if the desalinator is coupled with a thermal power plant. In this case, the MSF desalination plant is operated with approximately 120o C of waste heat recovered from the power plant.

The investment costs as well as the operating costs exhibit strong economies of scale. Consequently, there is a preference for large-scale desalinators with capacities of up to 500,000 cubic metres per day. Due to the high investment costs as well as the functional requirements of control technology, such plants must be operated around the clock.

Reverse osmosis

In desalination by reverse osmosis (RO), the pre-treated raw water is pressed through a membrane that is permeable to pure water but virtually impermeable to salt molecules and organic compounds. Part of the raw water is drained off as concentrate. The permeate will still contain a certain amount of salt, which depends on the quality of the raw water. If the brackish water contains less than 10 g/l of dissolved salts, the permeate can be used as drinking water with no need for further treatment. Sea water (35 g/l) and water with a higher salt content must be desalinated in several stages in order to achieve a residual salt content of 1 g/l.

RO plants are series-produced in all sizes, ranging from large-scale plants with capacities of several 1,000 cubic metres per day to small household units designed to supply 12 litres per day. The latter are operated with pressure from the water mains and merely serve to improve the quality of the tap water.

RO plants make up about one-fifth of the world's total installed desalination capacity. In contrast to multiple-stage flash designs, RO plants can achieve favourable specific investment costs and energy consumption levels even with low-output models.

Significant progress in the production of the membranes has lowered the share of the system costs accounted for by these components from 30% to 10%. However, the membranes still have to be replaced every 2-5 years. Moreover, improper operation can easily lead to damages and premature failure of the membrane.

Energy requirement

The amount of pressure - and thus the amount of energy - required for desalination by reverse osmosis primarily depends on the salt content of the raw water. In practice, about twice the amount of osmotic pressure is necessary. In other words, 4-12 kWh of electrical energy are required to drive the pump for every cubic metre of drinking water. Some distillation methods consume the same amount of energy as auxiliary energy alone. RO is thus the most energy-efficient desalination technique, especially for brackish water. If the demand for water is no higher than 1-2 cubic metres per day, a photovoltaic plant is also an economical energy-supply option. For larger plants, however, a diesel generator is a cheaper source of electricity.

In any event, qualified personnel and a good supply of spare parts are necessary for RO plants.

Pre-treatment of the raw water

Depending on the composition, various substances in raw water must be neutralised, thrown down or filtered out. The filters and chemicals required for this pre-treatment process are not very costly in industrialised countries but may be difficult to procure in developing countries.

Costs of desalination by reverse osmosis

The investment costs of an RO plant are relatively low. A plant for the desalination of brackish water (salt content 4 g/l) with a capacity of 10 cubic metres per day costs approximately DM 10,000. Additional costs on roughly the same scale also arise for energy supply, facilities for pre-treating the raw water and storage tanks.

The energy and operating costs strongly depend on the quality of the raw water. However, if brackish water is not too salty, the costs of RO desalination are generally lower than those of other desalination methods.

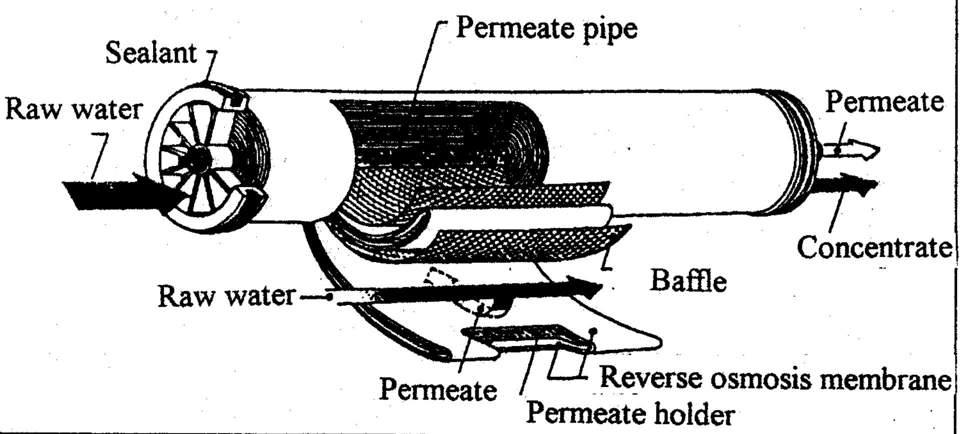
Operation and maintenance

The operation and maintenance of RO plants calls for qualified technical personnel. The plants' mode of operation must be adjusted precisely to the quality of the water. A detailed chemical analysis of the raw water is necessary for this. The composition of well water, for example, can change from one season to the next, making a post-adjustment necessary.

Consequences of improper operation

Improper operation can cause the membrane to become clogged, sharply reducing the plant's output. In this case, the membrane must be flushed out or replaced by a qualified technician. If the plant is not in operation for a longer period of time, the membrane may germinate and become useless. A liquid disinfectant must be poured in to prevent this. After the plant is put back into operation, the permeate will initially still contain some residues which can have a harmful effect on health if it is used as drinking water.

Design of a Reverse Osmosis Module



Use in developing countries

RO plants are technically very well suited to the desalination of brackish water in small, decentralised areas. However, the need for qualified operating personnel and the dependence on spare parts and ancillary substances or materials detract from the benefits of using such plants in rural areas of developing countries. For this reason, RO plants cannot be considered an appropriate technology for this application.

Literature:

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Solare Meer- und Brackwasserentsalzung [Solar desalination of sea and brackish water]Partial evaluation on the policy paper "Nutzung Regenerativer Energiequellen in Entwicklungsländern" [Utilization of renewable energy sources in developing countries], Munich, 1987.

Study of various research projects on the development of improved solar stills. Provides a good overview of the various technology strategies/options with a realistic assessment of the potential for technical and economic development.

2 V. Janisch, H. Drechsel:
Solare Meerwasser-Entsalzung [Solar sea water desalination] ISBN 3-528-02006-7 GATE, Vieweg Verlag, 1984

Overview of the historical development and various designs for solar stills. The book describes factors influencing efficiency, defines the area in which the use of solar stills is worthwhile and also presents other desalination methods. Four designs are described in more detail.

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Solar-Powered Desalination - A Case Study from Botswana IDRC, Ottawa, Canada, 1990 ISBN 0-88936-554-7

Summary of the results of a field study conducted in Botswana in 1985-1988 on solar stills to supply water from brackish wells/boreholes for small settlements in remote areas. The economic analysis showed that solar distillation has cost-related advantages over the supply of drinking water by truck, although only a minimal improvement is achieved. Includes a detailed description of the designs employed, with drawings, lists of material, descriptions of installation and maintenance operations and a cost summary. Very up-to-date.

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Solar Distillation
A Practical Study of a Wide Range of Stills and Their Optimum Design, Construction and Performance Pergamon Press, 1982 ISBN 0-08-028679-8

Introduction to the physico-technical basics of solar distillation with a precise study of energy flows and the influence of various designs and ambient conditions on efficiency. Extensive bibliography.

5 J. Gordes, H. McCracken:
Understanding Solar Stills VITA Technical Paper Arlington, USA, 1985 ISBN 0-86619-248-4

Detailed technical and economic observations on the construction of solar stills with valuable tips on choice of materials for the individual components, not only from the standpoint of efficiency but also with the cost factor and lifetime in mind.

6 R. Hasse:
Rainwater Reservoirs; Above Ground Structures for Roof Catchment GATE/Vieweg, 1989 ISBN 3-528-02049-0

Instructions for the construction of cisterns to collect rainwater.

7 R.N. Bhatt:
Solar Stills: Simple and Effective in: GEDA File, Sept. 92, Vol. 5, No. 3 Gujarat Energy Development Agency Vadodara, India, 1992

Report on experience with the application of solar stills in India. Stills with fibreglass basins and glass covers are used to produce drinking water as well as distilled water for other applications. A fine-mesh screen is mounted over the still to protect the glass against breakage. The sealants are made of tarred strips.

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