SOLAR DISTILLATION

Introduction

Solar distillation is a relatively simple treatment of brackish (i.e. contain dissolved salts) water supplies. Distillation is one of many processes that can be used for water purification and can use any heating source. Solar energy is a low tech option. In this process, water is evaporated, using the energy of the sun then the vapour condenses as pure water.This process removes salts and other impurities.

Solar distillation is used to produce drinking water or to produce pure water for lead acid batteries, laboratories, hospitals and in producing commercial products such as rose water. It is recommended that drinking water has 100 to 1000 mg/l of salt to maintain electrolyte levels and for taste. Some saline water may need to be added to the distilled water for acceptable drinking water.

Solar water distillation is a very old technology. An early large-scale solar still was built in 1872 to supply a mining community in Chile with drinking water. It has been used for emergency situations including the introduction of inflatable stills for life boats by the navy.

There are a number of other approaches to desalination, such as photovoltaic powered reverseosmosis, for which small-scale commercially available equipment is available; solar distillation has to be compared with these options to determine its appropriateness to any situation. If treatment of polluted water is required rather than desalination, slow sand filtration is a low cost option.

Energy requirements for water distillation

The energy required to evaporate water, called the latent heat of vaporisation of water, is 2.26 Megajouls per kilogram (MJ/kg). This means that to produce 1 litre (i.e. 1 kg as the density of water is 1 kg/litre) of pure water by distilling brackish water requires a heat input of 2.26 MJ. This does not allow for the efficiency of the system used which will be less than 100%, or for any recovery of latent heat that is rejected when the water vapour is condensed.

It should be noted that, although 2.26 MJ/kg or 2260 kJ/kg is required to evaporate water, to pump water through 20 m head requires only 0.2 kJ/kg. Distillation is therefore normally considered only where there is no local source of fresh water that can be easily pumped or lifted.

How a simple solar still works

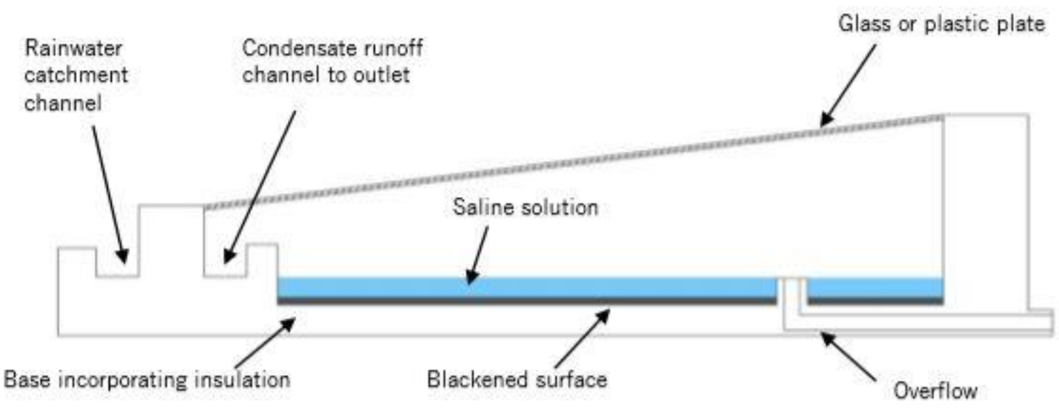

Figure 1: Shows a single-basin still. Illustration: Martin Bounds.

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The main features are the same for all solar stills. The solar radiation is transmitted through the glass or plastic cover and captured by a black surface at the bottom of the still. A shallow layer of water absorbs the heat which then produces vapour within the chamber of the still. This layer should be 20 mm deep for best performance.

Design objectives for an efficient solar still For high efficiency the solar still should maintain

- a high feed (undistilled) water temperature
- a large temperature difference between feed water and condensing surface
- low vapour leakage.

A high feed water temperature can be achieved if:

- a high proportion of incoming radiation is absorbed by the feed water as heat. Hence low absorption glazing and a good radiation absorbing surface are required
- heat losses from the floor and walls are kept low
- the water is shallow so there is not so much to heat.

A large temperature difference can be achieved if:

- the condensing surface absorbs little or none of the incoming radiation
- condensing water dissipates heat which must be removed rapidly from the condensing surface by, for example, a second flow of water or air, or by condensing at night.

Stills

Single-basin stills have been much studied and their behaviour is well understood. The efficiency of solar stills which are well-constructed and maintained is about 50% although typical efficiencies can be 25%. Daily output as a function of solar irradiation is greatest in the early evening when the feed water is still hot but when outside temperatures are falling. At very high air temperatures such as over 45°C, the plate can become too warm and condensation on it can become problematic, leading to loss of efficiency.

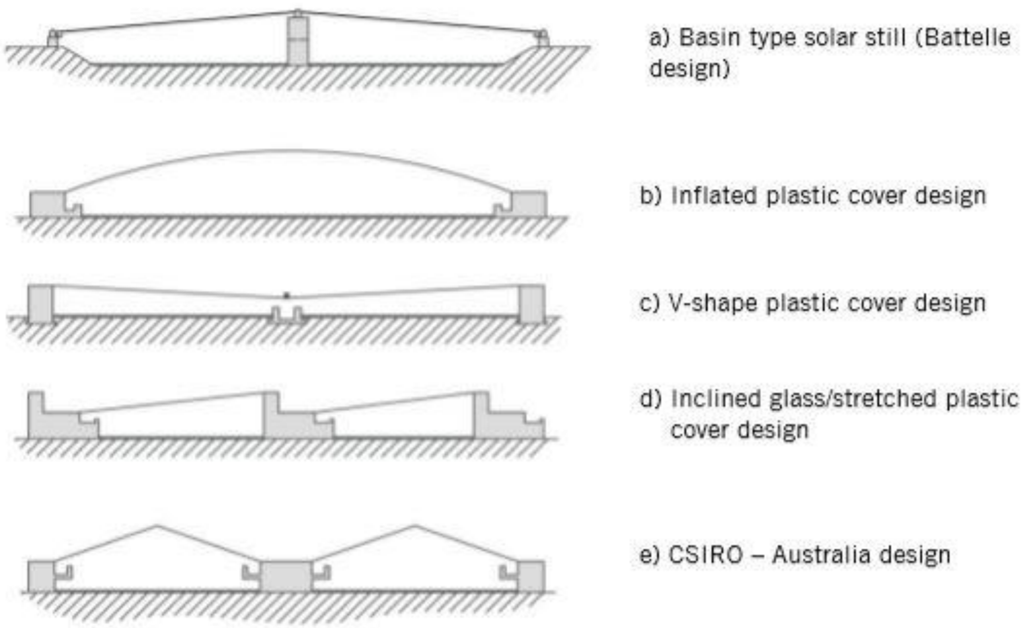

Figure 2: Examples of solar sill designs. Illustration: Martin Bounds.

Some problems with solar stills which would reduce their efficiency include:-

- Poor fitting and joints, which increase colder air flow from outside into the still Cracking, breakage or scratches on glass, which reduce solar transmission or let in air
- Growth of algae and deposition of dust, bird droppings, etc. To avoid this the stills need to be cleaned regularly every few days
- Damage over time to the blackened absorbing surface
- Accumulation of salt on the bottom, which needs to be removed periodically
- The saline water in the still is too deep, or dries out. The depth needs to be maintained at around 20 mm

The cover can be either glass or plastic. Glass is preferable to plastic because most plastic degrades in the long term due to ultra violet light from sunlight and because it is more difficult for water to condense onto it. Tempered low-iron glass is the best material to use because it is highly transparent and not easily damaged (Scharl & Harrs, 1993). However, if this is too expensive or unavailable, normal window glass can be used. This has to be 4 mm think or more to reduce breakages. Plastic (such as polyethylene) can be used for short-term use.

Stills with a single sloping cover with the back made from an insulating material do not suffer from a very low angle cover plate at the back reflecting sunlight and thus reducing efficiency. It is important for greater efficiency that the water condenses on the plate as a film rather than as droplets, which tend to drop back into the saline water. For this reason the plate is set at an angle of 10 to 20°. The condensate film is then likely to run down the plate and into the run off channel.

Brick, sand concrete or waterproofed concrete can be used for the basin of a long-life still if it is to be manufactured on-site, but for factory-manufactured stills, prefabricated ferro-concrete can be used. Moulding of stills from fibreglass was tried in Botswana (Yates, Woto & Tlhage, 1990) but in this case was more expensive than a brick still and more difficult to insulate sufficiently, but has the advantage of the stills being transportable.

By placing a fan in the still it is possible to increase evaporation rates. However, the increase is not large and there is also the extra cost and complication of including and powering a fan in what is essentially quite a simple piece of equipment. Fan assisted solar desalination would only really be useful if a particular level of output is needed but the area occupied by the stills is restricted, as fan assistance can enable the area occupied by a still to be reduced for a given output.

The Mexican still

In the Mexican still two stills such as the above are fixed together to form a triangular tent shape. The glass plates can be supported from below at the apex where they join, but if they are not and just lean against each other, fixed with sealant, this increases the fragility of the still and limits the area even further of each of the glass plates.

The Brace Research Institute still

This is essentially a still as shown in the above drawing (Figure 1). However the stills are placed next to each other over the width of say 10 metres of the distillation plant. Lengthwise, the unit such as shown is built over a considerable distance, such as 15 metres. Glass plates are placed along the length of the still and simply joined with sealant. Units of this size also have two small weirs lengthwise to encourage saline water to flow along the full length of the still. A project of this type was set up by the Brace Research Institute, McGill University, Canada in Haiti. The scale of the unit requires caretakers to be trained in the maintenance of it, and maintenance requirements are quite considerable.

Multiple-effect basin stills have two or more compartments. The condensing surface of the lower compartment is the floor of the upper compartment. The heat given off by the condensing vapour provides energy to vaporize the feed water above. Efficiency is therefore greater than for a singlebasin still typically being 35% or more but the cost and complexity are correspondingly higher.

Wick stills - In a wick still, the feed water flows slowly through a porous, radiation-absorbing pad (the wick). Two advantages are claimed over basin stills. First, the wick can be tilted so that the feed water presents a better angle to the sun (reducing reflection and presenting a large effective area). Second, less feed water is in the still at any time and so the water is heated more quickly and to a higher temperature. Simple wick stills are more efficient than basin stills and some designs are claimed to cost less than a basin still of the same output.

Some designs have been developed which incorporate absorbent or film-type materials to increase the surface area of evaporation – e.g. an article on the design developed by G.N. Tiwari of the Indian Institute of Technology, New Delhi, was published in New Scientist.

Use of Reflector
The inside walls of the still can incorporate a reflective coating, such as aluminium foil, to increase the reflection of heat energy onto the evaporating water. It is not known how far this has helped to improve the efficiency of the still.

Inverted Absorber Solar Stills
Heat is absorbed from the underside of the still to improve efficiency. This allows that condenser plate and the collector plate to be separate. There are several designs of inverted absorber from the fairly simple to more complex designs.

Spherical Still
In a design developed by the Thermal and Solar Laboratory at Claude Bernard University, Lyons, France, a trough, where the saline water is placed, is positioned in the centre of a hollow transparent plastic sphere. Distillate water condenses on the inside surface of the sphere and is collected by a mechanical windscreen type wiper blade which forces the condensed water to fall to the bottom of the sphere to be collected. There seems to be a small improvement in efficiency compared with a conventional solar still, but the greater cost of this still might cancel out this advantage. [World Water]

Inclined Stills
The aim of inclining a still is to increase the solar radiation, by catching it head on, rather than at an angle as with stills which lie flat. To do this constantly, as the sun rises and sets, would need someone to monitor the sun and turn the unit regularly, or a sophisticated automatic tracking and turning mechanism.

Condensate Heat Recovery Heat recovery from the energy given out when water vapour condenses has generally not been attempted with small-scale solar distillation, unlike with larger-scale systems. It is known that the Ben Gurion Institute, and more latterly the Technion Institute in Israel has undertaken some experiments with heat recovery. In the simplest system, saline water is made to flow over the outside of the condensation plate before entering the still, but then this would reduce the amount of solar radiation passing through the plate. There may be scope for further research to overcome current difficulties with attempting heat recovery from solar distillation.

Emergency still - To provide emergency drinking water on land, a very simple still can be made. It makes use of the moisture in the earth. All that is required is a plastic cover, a bowl or bucket, and a pebble.

Hybrid designs - There are a number of ways in which solar stills can usefully be combined with another function of technology. Three examples are given:

- Rainwater collection. By adding an external gutter, the still cover can be used for rainwater collection to supplement the solar still output.
- Greenhouse-solar still. The roof of a greenhouse can be used as the cover of a still.
- Supplementary heating. Waste heat from an engine or the condenser of a refrigerator can be used as an additional energy input.

Output of a solar still An approximate method of estimating the output of a solar still is given by:

$$Q = \frac{E \times G \times A}{L}$$

where:

Q = daily output of distilled water (litres/day)
E = overall efficiency
G = daily global solar irradiation (MJ/m^2)
L = The latent heat of vaportisation of water = 2.26 MJ/kg
A = aperture area of the still ie, the plan areas for a simple basin still (m^2)

In a typical country the average, daily, global solar irradiation is typically 18.0 MJ/m^2 (5 kWh/m^2). A simple basin still operates at an overall efficiency of about 30%. Hence the output per square metre of area is:

$$\text{daily output} = \frac{0.30 \times 18.0 \times 1}{2.26}$$
$$= 2.34 \text{ litres (per square metre)}$$

Performance varies between tropical locations but not significantly. An average output of 2.3 to 3.0 $litres/m^2/day$ is typical, the yearly output of a solar still is often therefore referred to as approximately one cubic metre per square metre, 1 $m^3/m^2/year$.

Experience

Despite a proliferation of more sophisticated designs such as TERI's solar desalination unit with offset collectors, the single-basin still has the best track record in the field. Hundreds of smaller stills are operating, in Africa and India.

The cost of pure water produced depends on:

- the cost of making the still
- the cost of the land
- the life of the still
- operating costs
- cost of the feed water
- the discount rate adopted
- the amount of water produced.

An example of costs of a solar still in India is Rs. 28000 for 15 m^2 approximately $575.00 for 15 m^2, or $38.3 per m^2. The price of land will normally be a small proportion of this in rural areas, but may be prohibitive in towns and cities. (See the TNAU website for details)

The life of a glass still is usually taken as 20 to 30 years but operating costs can be large especially to replace broken glass.

It is important that stills are regularly inspected and maintained to retain their efficiency and reduce deterioration. Damage, such as breakage of the collector plate, needs to be rectified.

Some companies, e.g. in the United States, Russia, India and South Africa, sell solar stills, largely for household use to produce up to about 50 litres per day.

Would a solar still suit your needs?

People need 1 or 2 litres of drinking water a day to live. The minimum requirement for normal life in developing countries (which includes cooking, cleaning and washing clothes) is 20 litres per day (in the industrialised countries 200 to 400 litres per day is typical). Yet some functions can be performed with salty water and a typical requirement for distilled water is 5 litres per person per day. Therefore 2 m^2 of still are needed for each person.

Solar stills should normally only be considered for removing dissolved salts from water. If there is a choice between brackish ground water or polluted surface water, it will usually be cheaper to use a slow sand filter or other treatment device. If there is no fresh water then the main alternatives are desalination, transportation and rainwater collection.

Big change starts small
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Unlike other techniques of desalination, solar stills are more attractive, the smaller the required output. The initial capital cost of stills is roughly proportional to capacity, whereas other methods have significant economies of scale. For the individual household, therefore, the solar still is most economic.

For outputs of 1 m^3/day or more, reverse osmosis or electro dialysis should be considered as an alternative to solar stills. Much will depend on the availability and price of electrical power.

For outputs of 200 m^3/day or more, vapour compression or flash evaporation will normally be least cost. The latter technology can have part of its energy requirement met by solar water heaters.

In many parts of the world, fresh water is transported from another region or location by boat, train, truck or pipeline. The cost of water transported by vehicles is typically of the same order of magnitude as that produced by solar stills. A pipeline may be less expensive for very large quantities.

Rainwater collection is an even simpler technique than solar distillation and is preferable in areas with 400 mm of rain annually, but requires a greater area and usually a larger storage tank. If ready-made collection surfaces exist (such as house roofs) these may provide a less expensive source for obtaining clean water (see the Rainwater Harvesting Technical Brief http://practicalaction.org/rainwater-harvesting-6).

Which solar still?

The single-basin still is the only design proven in the field. Multi-effect stills have the potential to be more economic but it would be as well to gain experience first with a single-basin still.

Further information

Factsheets & manuals

- Rainawater Harvesting Practical Action Technical Biref http://practicalaction.org/rainwaterharvesting-answers
- How to Construct a Solar Water Distiller , Practical Action South Asia. http://janathakshan.com/PDFs/SolarwaterDistiller%5Bpdf.pdf

Publications

- Malik A S et al, 1982, Solar Distillation Pergamon Press
- Bloemer, J. W., Washington D.C., Design of a Basin - Type Solar Still . UNT Digital Library. http://digital.library.unt.edu/ark:/67531/metadc11661/m1/9/
- *Solar Distillation Practice For Water Desalination Systems* Dr. G N Tiwari, Professor of Energy Studies, Indian Institute of Technology, Delhi, India Dr. A K Tiwari, Dept of Mechanical Engineering, National Institute of Technology, Raipur, India, 2008 Anshan Publishing, ISBN: 978 1905740 888

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TECHNICAL BRIEF