PDHonline Course E425 (1 PDH)

Solar Still – Distillation

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2020

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Solar still - Distillation

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COURSE CONTENT

It is expected that after 20 to 25 years from today there is almost no water left that is safe to drink. There is an important need for pure and clean drinking water in many developing countries as the available water is either brackish or containing harmful bacteria. Also in coastal areas where seawater is abundant but drinking water is rare, solar distillation is a helpful tool. This is also helpful to chemical industries for purification of water, where in impure water is purified before discharging the same to water bodies.

In solar distillation, water is evaporated and thus separated from salts and impurities and collected back as a pure water.

Why distilled water is costly?

Thermodynamics says that 2260 kJ/kg value of energy is required to evaporate 1 liter (1 kg) of water. Energy required in pumping of water is 0.2kJ/kg for 20m of head, which is considerably less compared to distillation process. Hence when nearby source of fresh water is available, solar distillation is not economical option.

Introduction

Water is the basic necessity for human along with food and air. There is almost no water left on Earth that is safe to drink without purification. Only 1% of Earth's water is in a fresh, liquid state, and nearly all of this is polluted by both diseases and toxic chemicals. For this reason, purification of water supplies is extremely important. Moreover, typical purification systems are easily damaged or compromised by disasters, natural or otherwise. This results in a very challenging situation for individuals trying to prepare for such situations, and keep themselves and their families safe from the myriad diseases and toxic chemicals present in untreated water. Everyone wants to find out the solution of above problem with the available sources of energy in order to achieve pure water.

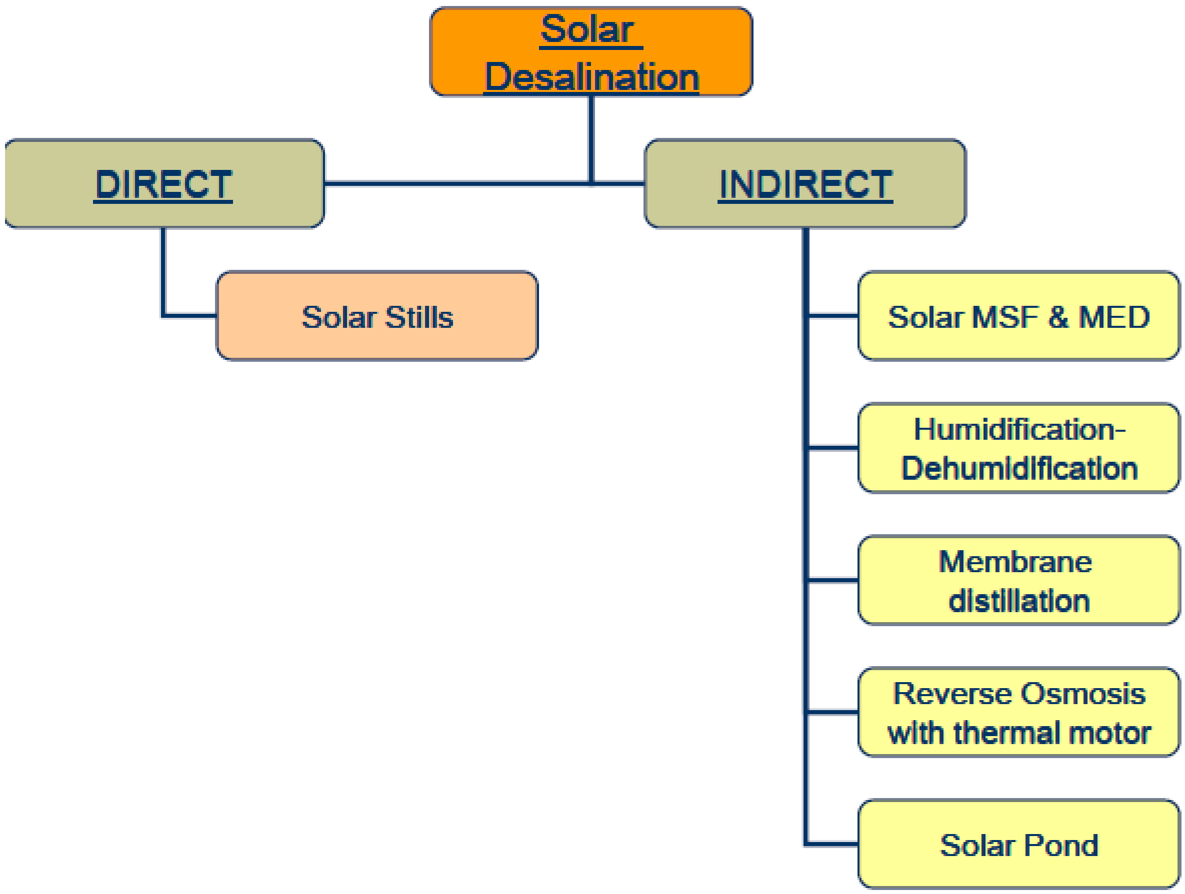
History of desalination

Aristotle was the first who explained the method to evaporate impure water and obtain potable drinking water. Solar distillation is practiced since very long time, especially by sailors at sea, who boiled the water and collected the vapor in sponge like cloth to get the sweet water. First documentation of solar distillation is reported by Arab alchemist in the 15th century. They used polished concave mirrors to focus solar radiation on a glass containing salt water to produce fresh water. Some earlier scientist have reported different methods of distillation like wide earthen pots were exposed to intense heat of solar radiation and vapor is collected in vases placed below it. In another method they have mentioned about obtaining fresh water from air (dehumidification of air).

In seventeenth century, French chemist Lavosier used large glass lenses mounted on structure to concentrate solar energy on distillation flask. First ever pattern in this field was registered by American scientists Wheeler and Evans. They have described greenhouse effect, rate of condensation and re evaporation etc. The first large solar distillation plant was built in Chile in 1872 to provide fresh water to workers of saltpeter silver mine. The plant was producing 4.91 l/m^2 of fresh water per day.

Figure 1 Solar distillation

Till second world war, very few solar distillation systems were existing. During 1930 to 40, dryness in California state resulted in increased interest in solar distillation. Immense urban development and industrial expansion after world war II created intensified need of fresh water as the sources of the same are dwindling day by day and there took place enormous growth in solar still development process.



Working Principle

Two major desalination method exists today, namely phase change by thermal heating and membrane or single phase process. Both process requires pre-treatment of water to prevent scaling, foaming, corrosion, biological growth, fouling etc. Seawater is chlorinated to avoid growth of seaweed and seashells in pipes. In addition, anti-scale and anti-foam additives are also dosed in sea water to prevent scaling and better heat transfer. Among different distillation methods, solar distillation is simple technology, easy to make and operate system. Solar still uses greenhouse effect to evaporate water. In its basic arrangement, it consists of a basin, roof and distilled water reservoir.

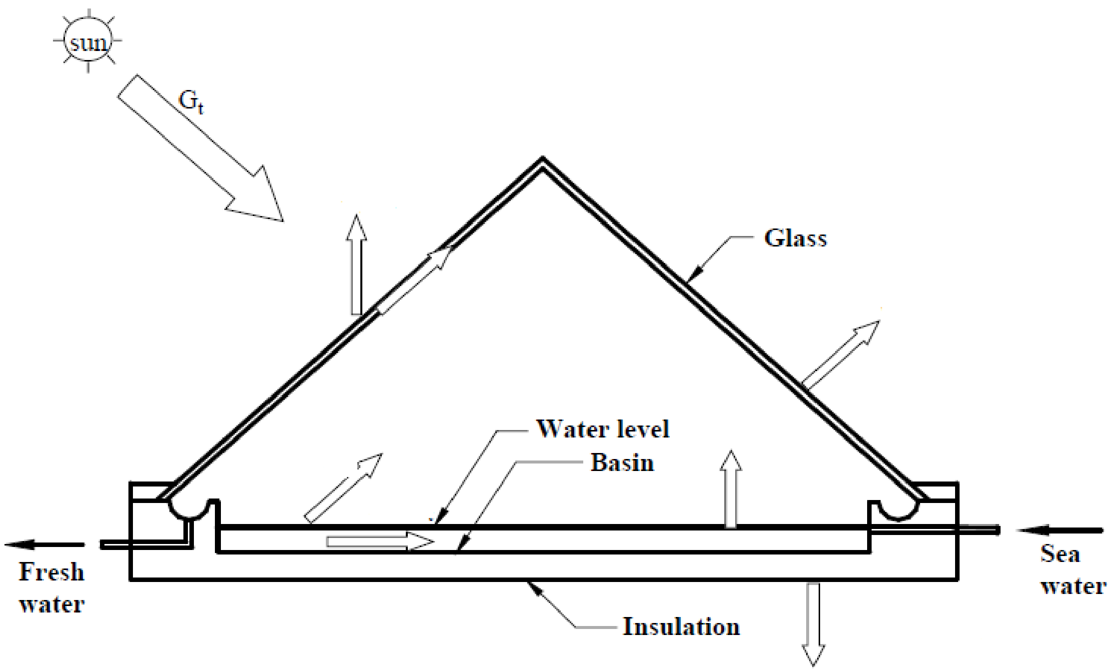


Figure 2 Simple solar still for solar water distillation

Figure 2 shows a simple solar still, in which constant amount of water is supplied in basin. Solar radiation passes through inverted V shaped glass cover and absorbed by blackened surface at the bottom of the basin. Heating of water makes it evaporate and condense on glass surface, which is later collected in reservoir through pipes. Glass roof helps to tap the sunlight and prevent it from escaping back to environment. It also helps to prevent wind loss. Film condensation results into effective condensate collection from the roof of solar still and to promote the same, roof plate is inclined at 10 to 20 degree with horizontal, higher than that will result into drop condensation.

Basin is constructed from cement, galvanized iron sheet or fiber reinforced plastic. Brick, sand and concrete type of basin can be made on site, while fabricated units are factory manufactured. Glass or plastic is used for roof top. Due to evaporation of water, remaining water becomes concentrate salt solution and it results in formation of salt layer. Frequent flushing is necessary to prevent salt precipitation at the bottom of the basin. Use of fan will increase evaporation rate and will not add much to power consumption. Inner surface of still can have reflective coating to increase the reflection. Different arrangement for roof of solar still are shown in figure 3.

In a sea water based desalination plant, three kg of sea water produce one kg of fresh water and extracted salt (brine) is discharged back to sea where it is diluted again. Normally salt is not recovered but for a specific application, if salt is required to be separated the concentration needs to be ten times and lot of energy is needed for separation of salt which is uneconomical. Production of salt in a salt pans near sunny seashore is economical option to produce salt.

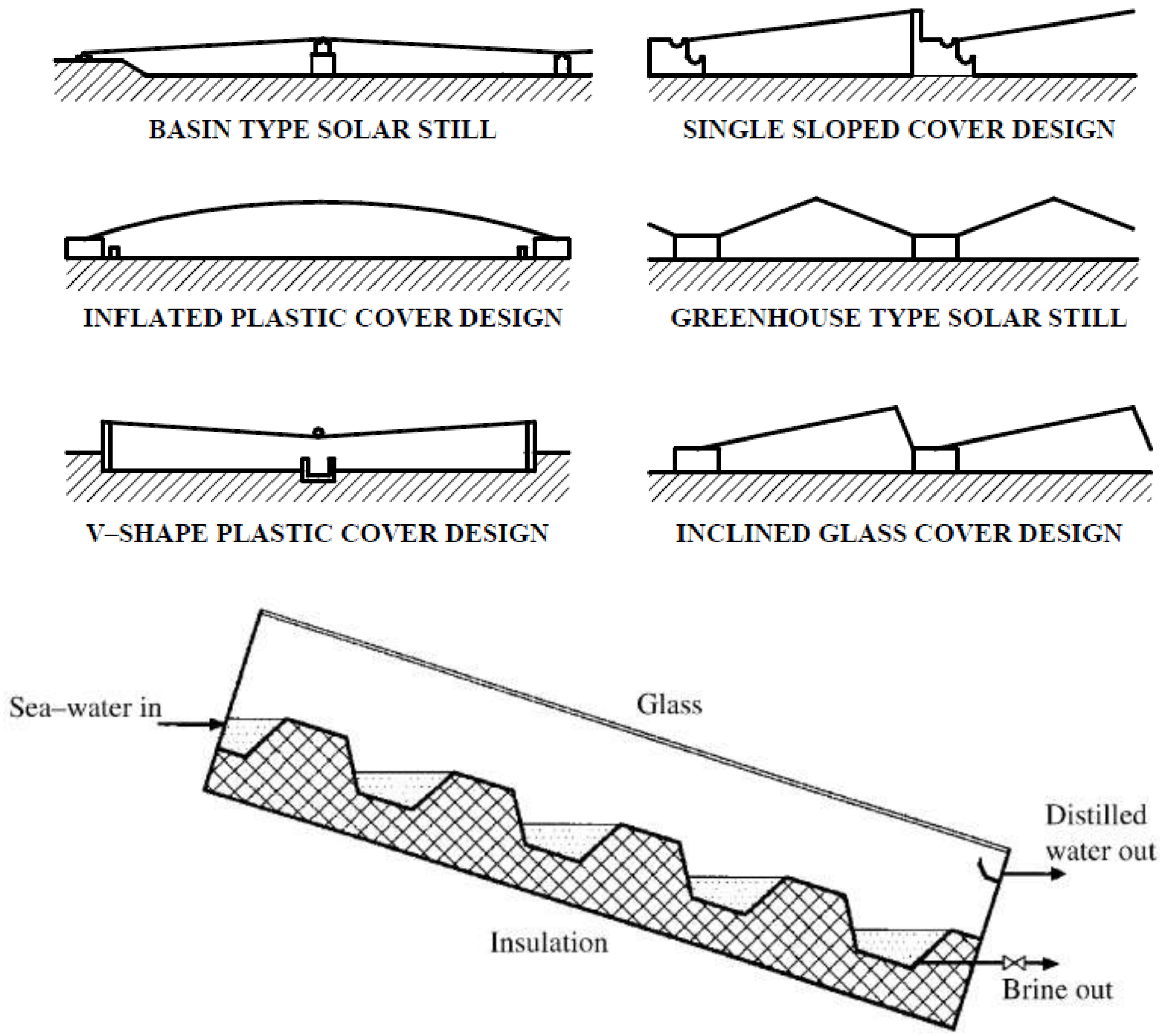


Figure 3 Different roof designs

Performance of solar still

Mass of distilled water collected per second is given by following equation,

$$mass\ of\ water = m_w = {}^{q}/_{h_{fg}} \qquad (1)$$

Where q is heat transfer and h_{fg} is latent heat of evaporation

$$q = 0.0163\ h_{cw}(P_w - P_g) \qquad (2)$$

Equation 2 is an empirical relation given by Dunkle, where h_{cw} is convective heat transfer co-efficient, P_w is partial vapor pressure at water temperature and P_g is partial vapor pressure at glass temperature. Convective heat transfer co-efficient can be obtained from the following equation 3.

$$N_u = \frac{h_{cd} d}{k} = C(Gr\ Pr)^n \qquad (3)$$

In above equation N_u stands for Nusselt Number, Gr stands for Grashof Number and pr stands for Prandtl Number, k stands for conductivity of air inside the still and d stands for characteristic length (average distance between glass and water) of still.

Following parameters affects solar distillation performance:

1. Water depth in a basin
2. Solar radiation intensity
3. Cover (roof) inclination and its material
4. Feed water temperature

Approximately 1 to 4 l/m^2/day is typical water distillation rate and generalized equation for calculating the same is given as equation 4.

$$mass\ of\ water = \frac{I_r \times n \times A}{2.3} \qquad (4)$$

Where I_r is global solar irradiation in MJ/m^2, n is efficiency of solar still and A is area of still in m^2, water collected is given in liters per day.

Objectives of solar still

Following working condition needs to be maintained for higher working efficiency of the solar still.

1. Supply water temperature should be as high as possible.
2. Minimum vapor leakage
3. Minimum heat loss from the bottom of the still and side walls.
4. Water depth should be minimum.

5. The condensing surface should absorb as little heat as possible.

Worldwide solar desalination

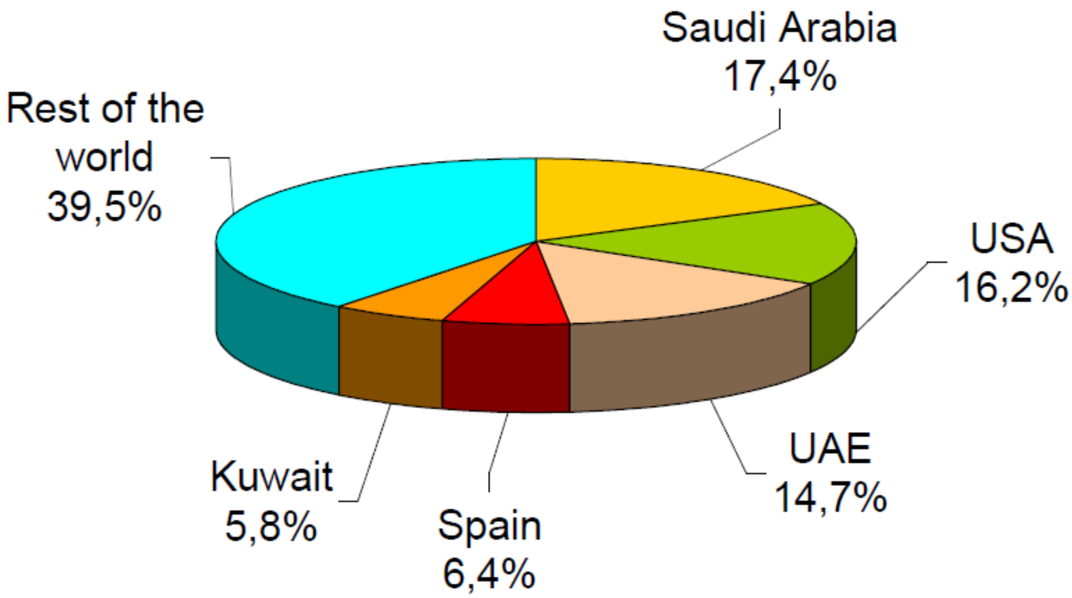


Figure 4 Worldwide solar desalination scenario

As shown in figure 4 Middle East countries are largest consumers of solar desalination plants. More than 50% of installations are in these countries whereas USA has 16%, Europe and Asia has 10% and Africa has around 6%.

Use of desalination

It is used for industry, human or agricultural applications. Many industries like petroleum, chemical etc need large quantity of pure water which contribute to one third of total desalination need. Human consumption contributes to 60% of total installed capacity and rest goes to agricultural use. In addition it is also used by military, navy and tourism services. As per International Desalination Association, out of total installed capacity 50 million m^3/day is produced. 46% of that comes from solar thermal distillation process.

Types of still

Single still basins are simple in construction and have efficiency around 25%. Multiple effect basin stills have two or more compartment in which condensing surface of lower compartment is the floor of the upper compartment. Efficiency of this type of basin is around 35%.

Further basins are wick type, in which feed water flows at very slow rate through a porous wick. The wick is kept inclined so that water surface has more exposure to solar radiation and minimum water is kept in a still hence evaporation becomes faster compared to basin type of still.

Other alternatives of solar still

Due to contact between salty water and collector surface, gradually it may corrode or scaled and its efficiency decreases. Some alternative arrangements for desalination are discussed here: They are either a phase change process or membrane process.

1. Humidification-dehumidification of air

In this method sea water is heated by solar collector and then sprayed on the honeycomb surface of humidifier. Air is passed through this honeycomb surface, which makes it hot and humidified. This hot and humidified air is taken to condensation area made of feed water tubes carrying cool water. Moisture of air separates and condenses on condenser surface. Capacity of such system is 10 to 20 liter/m^2/day.

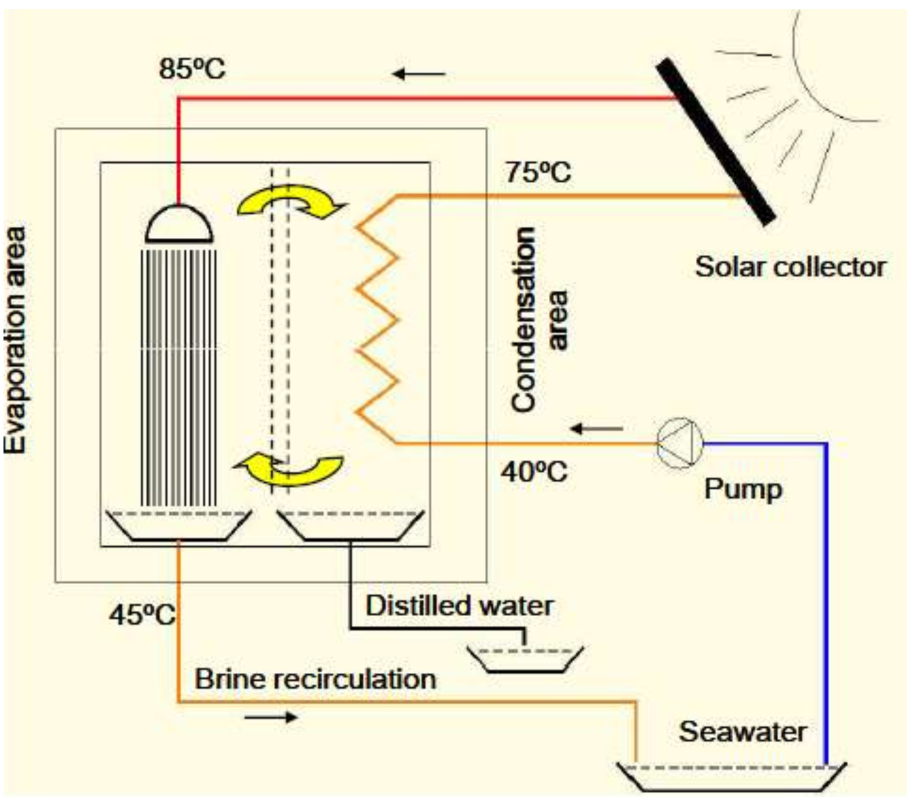


Figure 5 Humidification – dehumidification method

2. Multi effect distillation and multi stage flash distillation

In this method, condensing steam is used to preheat the feed water (sea water). As shown in figure 6, feed water heat is heated in multiple stages. Some of the water evaporates and flows in the tubes of the next stage, heating and evaporating more water, Thus each stage uses energy from the previous stage.

In multi stage flash distillation, sea water is desalinated by flashing a portion of water into steam in multiple stages. This method is conventionally used for large scale desalination of sea water.

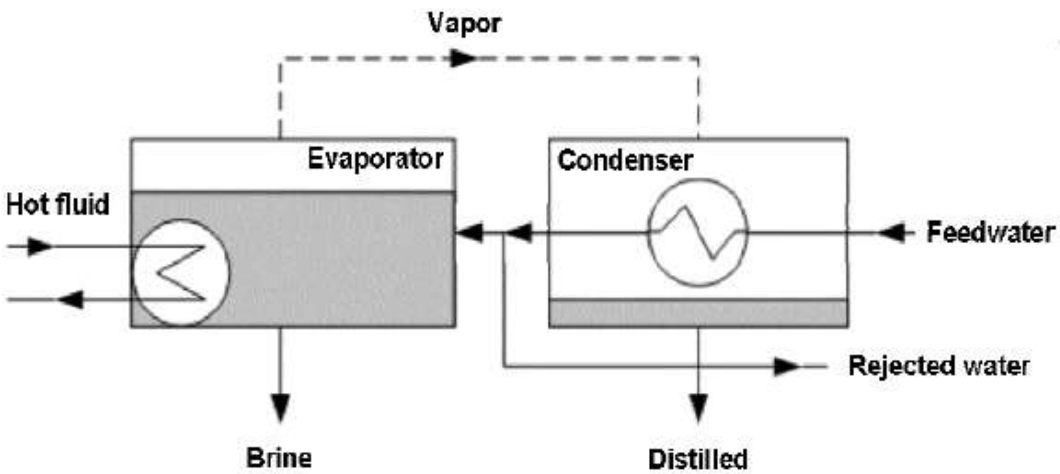


Figure 6 Multi effect distillation

3. Membrane distillation

This is a reverse osmosis process in which two solutions having different salt concentrations are separated by a semi permeable membrane. In this process, fresh water migrates from lower concentration to higher concentration side. This process stops at osmotic pressure and beyond that flow turns opposite i.e. from high concentration to low concentration which is called reverse osmosis. As shown in figure 7, feed water is pressurized at higher than osmotic pressure and pass through membrane. Majority of dissolved solids are removed there.

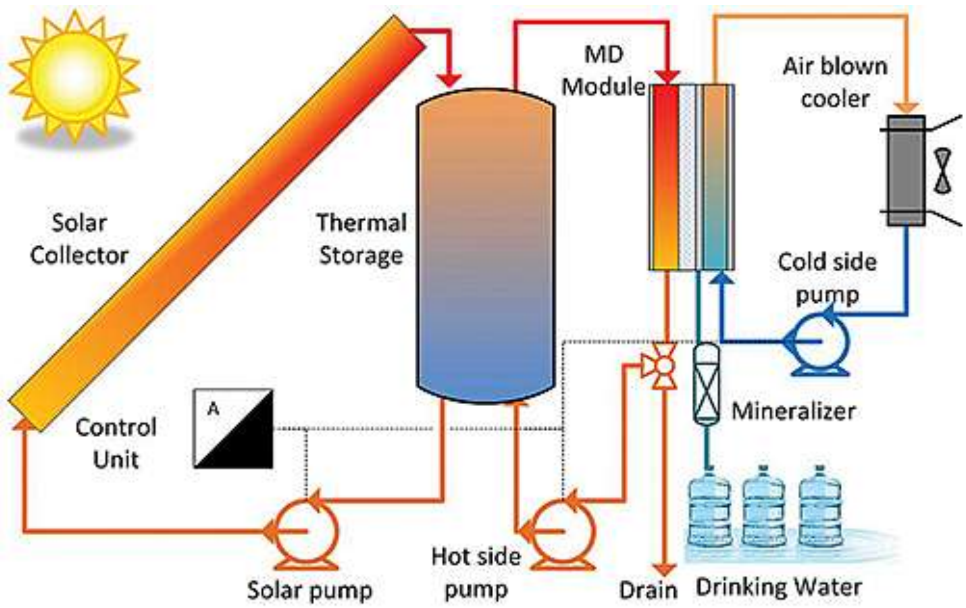


Figure 7 Membrane distillation

Water produced by thermal desalination process is quite pure as it has only few grams of salt per ton. Though distilled water does not comply WHO recommendations for drinking but consumed in small amount is not an issue. The problem with distilled water is storage for a long duration as being acidic in nature, it becomes corrosive and contaminated and hence for human consumption it needs to be mineralized and chlorinated.

Selection of desalination process

Following aspects are to be considered for solar desalination process

1. Suitability of process
2. Energy consumption
3. Amount of fresh water required
4. Sea water pre treatment required
5. Capital cost of equipment
6. Land availability and cost

To meet the increasing water need human beings has to develop use of wind, solar and other renewable technologies. Solar distillation is one of the rapidly emerging technology to meet tomorrow's environmental need.