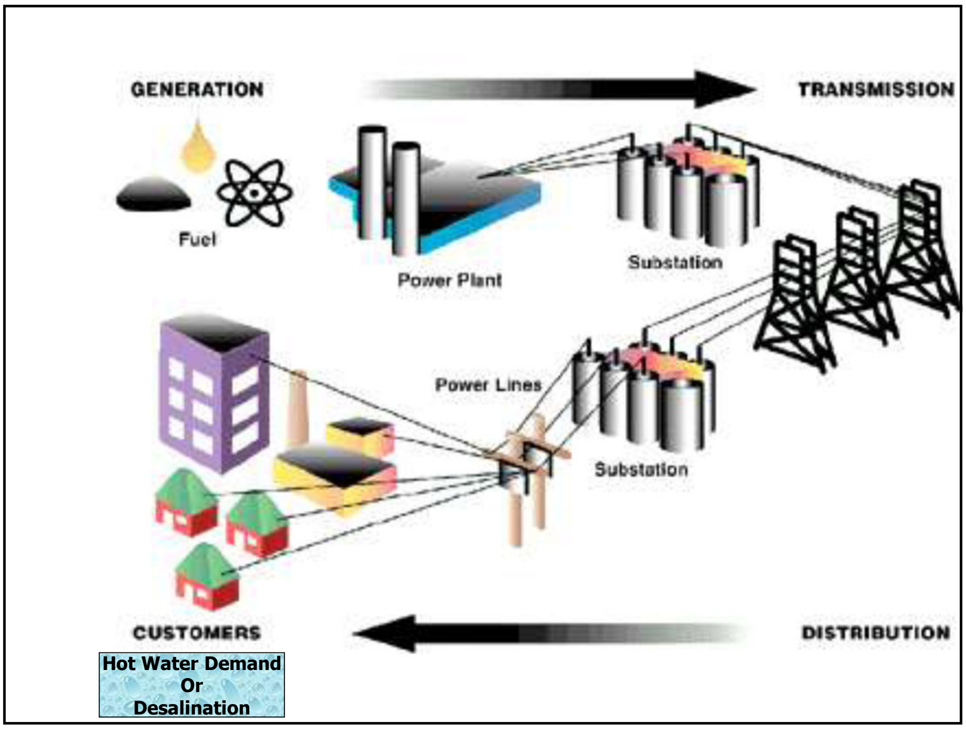
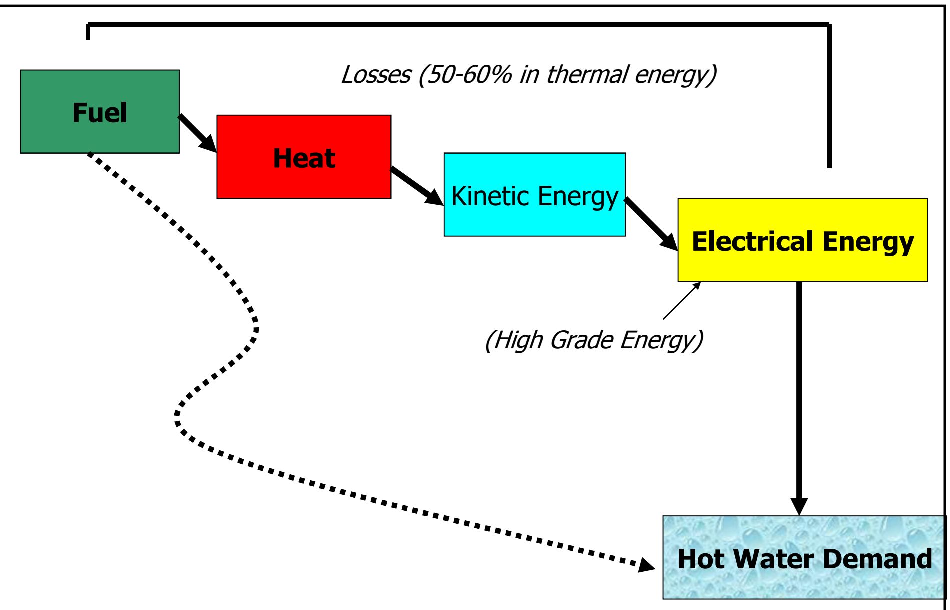
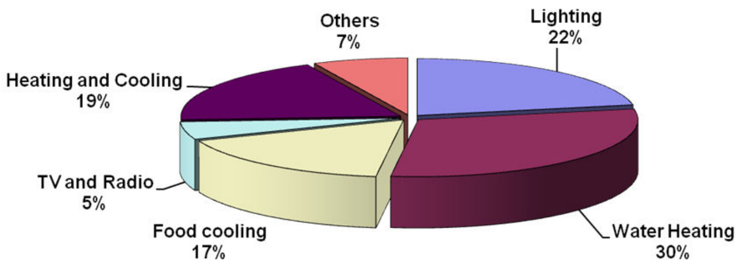
Solar Desalination Systems





Electricity consumption in Residential sector



- Hot water consume about 12% of total national electricity **3440 GWh**

Source: General electric company of Libya (GECOL)

WATER DESALINATION TECHNOLOGY

Water is essential to life. The importance of supplying potable water can hardly be overstressed. Water is one of the most abundant resources on earth, covering three fourths of the planet's surface. About 97% of the earth's water is saltwater in the oceans and 3% (about 36 million km^3) is freshwater contained in the poles (in the form of ice), ground water, lakes, and rivers, which supply most human and animal needs. Nearly 70% from this tiny 3% of the world's freshwater is frozen in glaciers, permanent snow cover, ice, and permafrost. Thirty percent of all freshwater is underground, most of it in deep, hard-to-reach aquifers. Lakes and rivers together contain just a little more than 0.25% of all freshwater; lakes contain most of it.

Of the total water consumption, about 70% is used by agriculture, 20% is used by the industry, and only 10% of the water consumed worldwide is used for household needs. It should be noted that, before considering the application of any desalination method, water conservation measures should be considered. For example, drip irrigation, using perforated plastic pipes to deliver water to crops, uses 30–70% less water than traditional methods and increases

WATER DESALINATION TECHNOLOGY

- * Potable water (fresh water) suitable for human consumption should not contain dissolved salts more than 500 ppm.
- * For agricultural purposes, water containing salt content of 1000 ppm is considered as the upper limit.
- * Potable water is required for domestic, agriculture and industries.
- * Some applications in industries like cooling purposes, sea water is feasible despite the corrosion problems while other industries use higher quality water than is acceptable for drinking water. Modern steam power generation plant need water with less than 10 ppm.
- * Potable/fresh water is available from rivers, lakes, ponds, wells, etc.
- * Underground saline/brackish water contains dissolved salts of about 2,000-2,500 ppm.

SOLAR DESALINATION TECHNIQUES

Potable Water	**Less than 550 ppm**
Requirement	**Domestic, Industries and Agriculture**
Sources of Potable Water	**Rivers, Lakes, Ponds, Wells etc.**
Demand of Potable Water	**15-25 litres / person / day (OLD)**
	100-125 litres / person / day (NEW)
Underground Saline Water	**2,000 – 2,500 ppm**
Sea Water	**30,000 – 50,000 ppm**

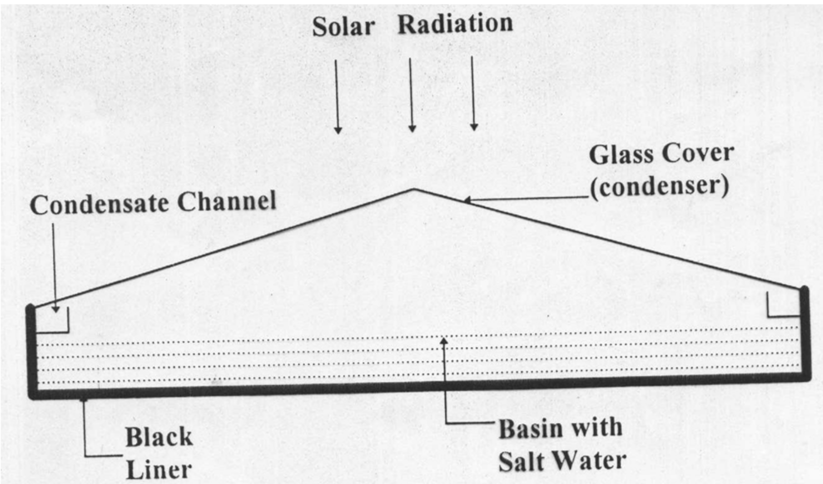
Desalination and Energy

The only nearly inexhaustible sources of water are the oceans. Their main drawback, however, is their high salinity. Therefore, it would be attractive to tackle the water-shortage problem by desalinizing of this water. *Desalinize*, in general, means to remove salt from seawater or generally saline water.

According to the World Health Organization (WHO), the permissible limit of salinity in water is 500 parts per million (ppm) and for special cases up to 1000 ppm. Most of the water available on earth has salinity up to 10,000 ppm, and seawater normally has salinity in the range of 35,000–45,000 ppm in the form of total dissolved salts. Excess brackishness causes the problem of bad taste, stomach problems, and laxative effects. The purpose of a desalination system is to clean or purify brackish water or seawater and supply water with total dissolved solids within the permissible limit of 500 ppm or less.

Desalination processes require significant quantities of energy to achieve separation of salts from seawater. This is highly significant because it is a recurrent cost that few of the water-short areas of the world can afford. Many countries in the Middle East, because of oil income, have enough money to invest and run desalination equipment. However, people in many other areas of the world have neither the cash nor the oil resources to allow them to develop in a similar manner. The installed capacity of desalinated water systems in the year 2000 was about 22 million m^3/d, which is expected to increase drastically in the next decades. The dramatic increase of desalinated water supply will create a series of problems, the most significant of which are those related to energy consumption and environmental pollution caused by the use of fossil fuels. It has been estimated that the production of 22 million m^3/d requires about 203 million tons of oil per annum (about 8.5 EJ/a or 2.36×10^{12} kWh/a of fuel).

Desalination by Solar Still



Schematic of basin-type solar still

COMPONENTS OF SINGLE EFFECT SOLAR STILL

١. Basin
٢. Black Liner
٣. Transparent Cover
٤. Condensate Channel
٥. Sealant
٦. Insulation
٧. Supply and Delivery System

BASIC REQUIREMENTS OF A GOOD SOLAR STILL

- Be easily assembled in the field,'
- Be constructed with locally available materials,
- Be light weight for ease of handling and transportation,
- Have an effective life of 10 to 20 Yrs.
- No requirement of any external power sources,
- Can also serve as a rainfall catchment surface,
- Is able to withstand prevailing winds,
- Materials used should not contaminate the distillate,
- Meet standard civil and structural engineering standards, and,
- Should be low in cost.

SOLAR STILL OUTPUT DEPENDS ON MANY PARAMETERS

1 Climatic Parameters

I. Solar Radiation
II. Ambient Temperature
III. Wind Speed
IV. Outside Humidity
V. Sky Conditions

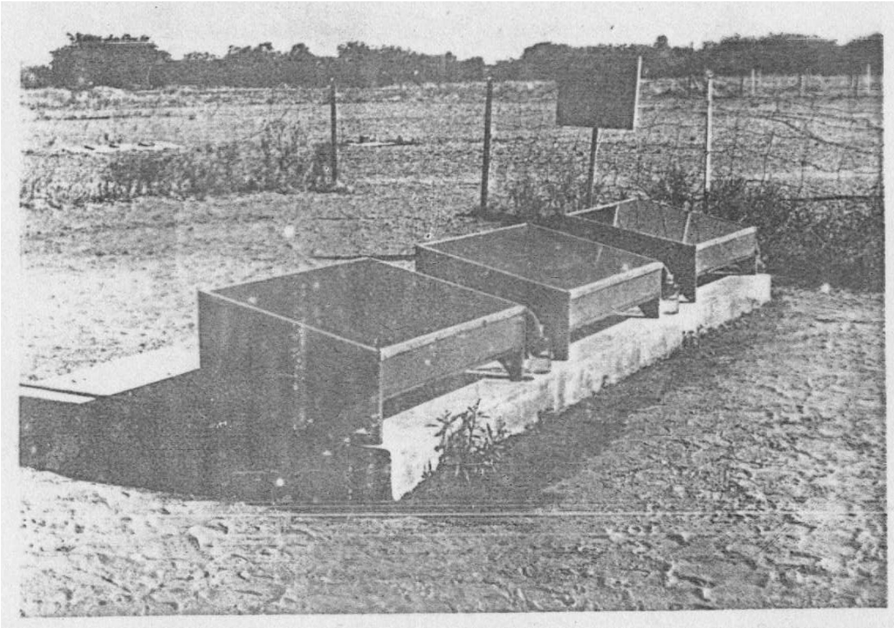
2 Design Parameters

I. Single slope or double slope
II. Glazing material
III. Bottom insulation
IV. Inclination of glazing
V. Spacing between water and glazing
VI. Type of solar still

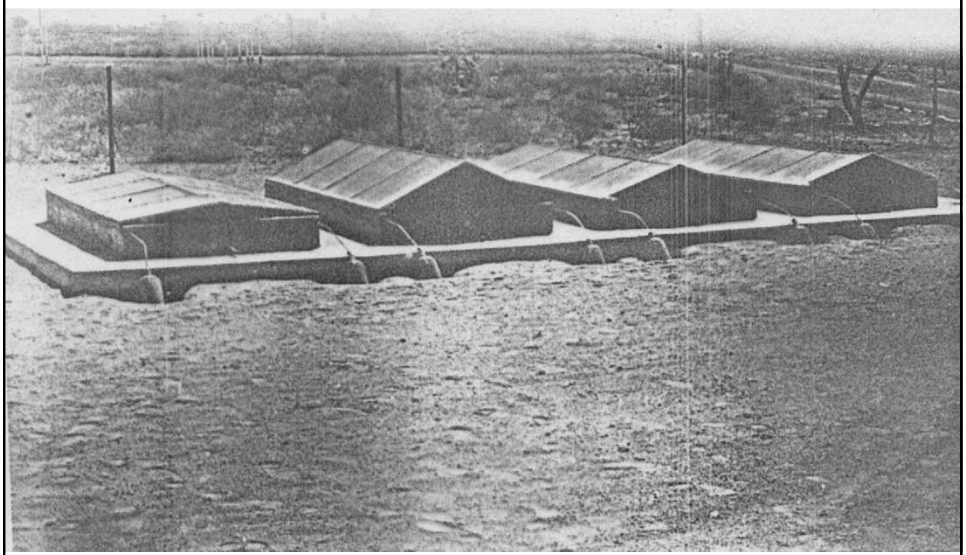
SOLAR STILL OUTPUT DEPENDS ON MANY PARAMETERS

3 Operational parameters

I. Water Depth
II. Preheating of Water
III. Colouring of Water
IV. Salinity of Water
V. Rate of Algae Growth
VI. Input Water supply arrangement (continuously or in batches)



Single slope experimental solar still



Double sloped experimental solar still

Main Problems of Solar Still

* Low distillate output per unit area
* Leakage of vapour through joints
* High maintenance ،
* Productivity decreases with time for a variety of reasons
* Cost per unit output is very high

Performance of Solar Stills

Solar stills are the most widely analyzed desalination systems. The performance of a conventional solar distillation system can be predicted by various methods, such as computer simulation, periodic and transient analysis, iteration methods, and numerical methods. In most of these methods, the basic internal heat and mass transfer relations, given by Dunkle (1961), are used.

Dunkle's (1961) procedure is summarized by Tiwari et al. (2003). According to this procedure, the hourly evaporation per square meter from a solar still is given by

$$q_{ew} = 0.0163 h_{cw} (P_w - P_g) \quad [W/m^2 \tag{8.26}$$

where

P_w = partial vapor pressure at water temperature (N/m^2).
P_g = partial vapor pressure at glass temperature (N/m^2).
h_{cw} = convective heat transfer coefficient from water surface to glass (W/m^2-°C).

The partial vapor pressures at the water and glass obtained from Eq. (5.21). The convective heat transfer coefficie from $P_s = 100(0.004516 + 0.0007178t_w - 2.649 \times 10^{-6} t_w^2 + 6.944 \times 10^{-7} t_w^3)$

$$Nu = \frac{h_{cw} d}{k} = C(Gr \times \Pr)^n$$

where

d = average spacing between water and glass surfaces (m).
k = thermal conductivity of humid air (W/m-°C).
C = constant.
n = constant.
Gr = Grashof number (dimensionless).
Pr = Prandl number (dimensionless).

The dimensionless quantities are given by

$$\mathrm{Gr} = \frac{g\beta\rho^2(\Delta T)d^3}{\mu^2} = \frac{g\beta(\Delta T)d^3}{\nu^2}$$

$$\Pr = \frac{c_p \mu}{k} \quad (8.29)$$

where

g = gravitational constant, = 9.81 m/s^2.
β = coefficient of volumetric expansion of fluid (1/K).
ρ = density of fluid (kg/m^3).
ΔT = temperature difference between surface and fluid (K).
μ = dynamic viscosity of fluid (kg/m-s).
ν = kinetic viscosity of fluid (m^2/s).
c_p = specific heat of fluid ((J/kg-K).

By using Eqs. (8.26) and (8.27), the hourly distillate output per square meter from a distiller unit ($\dot{m}_w$) is given by

$$\dot{m}_w = 3600 \frac{q_{ew}}{L_v} = 0.0163(P_w - P_g)\left(\frac{k}{d}\right)\left(\frac{3600}{L_v}\right) C(\mathrm{Gr} \times \Pr)^n \quad (8.30)$$

where L_v = latent heat of vaporization (kJ/kg),
or

$$\frac{\dot{m}_w}{R} = C(\mathrm{Gr} \times \mathrm{Pr})^n \tag{8.31}$$

where

$$R = 0.0163(P_w - P_g)\left(\frac{k}{d}\right)\left(\frac{3600}{L_v}\right) \tag{8.32}$$

It should be noted that, in the preceding equation, the product GrPr is known as the *Rayleigh number*, Ra. The constants C and n are calculated by regression analysis for known hourly distillate output (Dunkle, 1961), water and condensing cover temperatures, and design parameters for any shape and size of solar stills (Kumar and Tiwari, 1996).

The meteorological parameters—wind velocity, solar radiation, sky temperature, ambient temperature, salt concentration, algae formation on water, and mineral layers on the basin liner—affect significantly the performance of solar stills (Garg and Mann, 1976). For better performance of a conventional solar still, the following modifications were suggested by various researchers:

- Reducing the bottom loss coefficient.
- Reducing the water depth in a basin-multiwick solar still.
- Using a reflector.
- Using internal and external condensers.
- Using the back wall with cotton cloth.
- Using dyes.
- Using charcoal.
- Using an energy storage element.
- Using sponge cubes.
- Using a multiwick solar still.
- Condensing cover cooling.
- Using an inclined solar still.
- Increasing the evaporative area.

About a 10–15% change in the overall daily yield of solar stills due to variations in climatic and operational parameters within the expected range has been observed.

Different Empirical Correlations For Daily Yield From a Solar Still

S.N.	Performance Relations (l/m² d)	References
1.	$Mw = 0.216 + 0.00385\ I(t)$	Grunne et al (1962)
2.	$Mw = 0.0172\ I(t) - 1.1668$	Lawand & Boputiere (1970)
3.	$Mw = 0.000369\ I(t)^{1.64}$	Battele (1965)
4.	$Mw = 4.132 \times 10^{-3}\ I(t)\ [1+\{I(t) / 110\}]$	Zaki et al (1983)
5.	$Mw = 1.18 \times 10^{-4}\ I(t)^{1.64}$	Madani and Zaki (1989)
6.	$Mw = 0.0086\ I(t) + 0.0636Ta+0.0633V$	Garg and Mann (1976)
7.	$Mw = 0.013\ I(t) - 3.5969$	Garg and Mann (1976)
8.	$Mw = 0.1323\ W^{0.3}\ (T_{in} - T_a) - 1060$	Malik et al (1982)
9.	$Mw = 0.00354\ I(t)$	Maum et al (1970)
10.	$Mw = 2.295 \times 10^{-4}\ I(t) - 0.0139\ T_a+0.0185V - 0.433$	Natu et al (1979)

Where

I = Solar Intensity W/m²; t= time, s; m_w = Daily Distillate Output, kg/m²;

T = Temperature, °C; W = Humidity Ratio; V = Wind Speed (m/s)

Simple empirical correlations for daily yield from a solar still

Empirical relationship given by UK Center For Technology & Development

$$\dot{m} = \frac{A.E.G}{2.3}$$

A = Aperture area of the still in m^2
E = Efficiency of the still usually taken as 30%
G = Global radiation energy in kJ/m2-day
$\dot{m}$ = Daily Distillate Output (liters per day)

Example 1

A solar still has water and glass temperatures equal to 55°C and 45°C, respectively. The constants *C* and *n* are determined experimentally and found to be $C = 0.032$ and $n = 0.41$. If the convective heat transfer coefficient from water surface to glass is 2.48 W/m^2-K, estimate the hourly distillate output per square meter from the solar still.

Solution

From Eq. (5.21) and the temperatures of the water and glass, the partial pressures can be obtained as

$$\begin{aligned} P_w &= 100(0.004516 + 0.0007178 t_w - 2.649 x 10^{-6} t_w^2 + 6.944 \times 10^{-7} t_w^3) \\ &= 100(0.004516 + 0.0007178 \times 55 - 2.649 x 10^{-6} \times 55^2 \\ &\quad + 6.944 \times 10^{-7} \times 55^3) \\ &= 15.15 \text{ kPa} \end{aligned}$$

$$\begin{aligned} P_g &= 100(0.004516 + 0.0007178 t_g - 2.649 \times 10^{-6} t_g^2 + 6.944 \times 10^{-7} t_g^3) \\ &= 100(0.004516 + 0.0007178 \times 45 - 2.649 x 10^{-6} \\ &\quad \times 45^2 + 6.944 \times 10^{-7} \times 45^3) \\ &= 9.47 \text{ kPa} \end{aligned}$$

From Eq. (8.26),

$$
\begin{aligned}
q_{ew} &= 0.0163 h_{cw}(P_w - P_g) \\
&= 0.0163 \times 2.48(15.15 - 9.47) \times 10^3 \\
&= 229.6\ \text{W}/\text{m}^2
\end{aligned}
$$

From steam tables, the latent heat of vaporization at 55°C (water temperature) is 2370.1 kJ/kg.

From Eq. (8.30),

$$\dot{m}_w = 3600 \frac{q_{ew}}{L_v} = 3600 \frac{229.6}{2370.1 \times 1000} = 0.349\ \text{kg}/\text{m}^2$$

Example 2

If the following data were recorded in certain site, calculate the daily Production of a solar still by using **Grunne et al**, **Malik et al (1982)) and Madani and Zaki prediction empirical correlations**

I = Solar Intensity =850 W/m2

T = Temperature= 28 °C

V = Wind Speed =2 (m/s)

Solution

Mw =0.216+0.00385*I(t)   (Grunne et al,)
Mw=0.216+(0.00385*850)=3.47 (kg/m2)

Mw = 0.00354 I(t) (Malik et al (1982))
Mw = 0.00354*850 = 3.0 (kg/m2)

Mw = 0.0086 I(t) + 0.0636Ta+0.0633V (Madani and Zaki)
Mw = 0.0086*(850) + 0.0636(28)+0.0633*(2) = 7.4 (kg/m2)

CONCLUSIONS ON BASIN- TYPE SOLAR STILL

1. The solar still output (distillate) is a strong function of solar radiation on a horizontal surface. The distillate output increases linearly with the solar insolation for a given ambient temperature. If the ambient temperature increases or the wind velocity decreases, the heat loss from solar still decreases resulting in higher distillation rate. It is observed for each 10°C rise in ambient temperature the output increases by 10 percent.

2. The depth of water in the basin also effects the performance considerably. At lower basin depths, the thermal capacity will be lower and hence the increase in water temperature will be large resulting in higher output. However, it all depends on the insulation of the still. If there is no lnsulatlon, increase in water temperature will also increase the bottom heat loss. It has been observed that if the water depth increases from 1.2 cm to 30 cm the output of still decreases by 30 percent.

CONCLUSIONS ON BASIN- TYPE SOLAR STILL (contd.)

3 Number of transparent covers in a solar still do not increase the output since it increases the temperature of the inner cover resulting in lower condensation of water vapour.

4 Lower cover slope increases the output. From practical considerations a minimum cover slope of 10 deg. is suggested.

5 The maximum possible efficiency of a single basin solar still is about 60 percent.

6 For higher receipt of solar radiation and therefore the higher yield the long axis of the solar still should be placed in the East-West direction if the still is installed at a high latitude station. At low latitude stations the orientation has no effect on solar radiation receipt.

EXERCISES

(1)

A solar still has a water and glass temperature equal to 52.5°C and 41.3°C, respectively. The constants C and n are determined experimentally and are found to be $C = 0.054$ and $n = 0.38$. If the convective heat transfer coefficient from water surface to glass is 2.96 W/m^2-K, estimate the hourly distillate output per square meter from the solar still.

(2)

One of the solar still productivity enhancements method is the use of the solar desalination still combined with air conditioning system. Discuss this statement and support your answer with some published researches