ALMUSTAQBAL UNIVERSITY COLLEGE
Iraq – Babylon

RENEWABLE ENERGY TECHNOLOGY

Sustainable Path For a Carbon Free Future

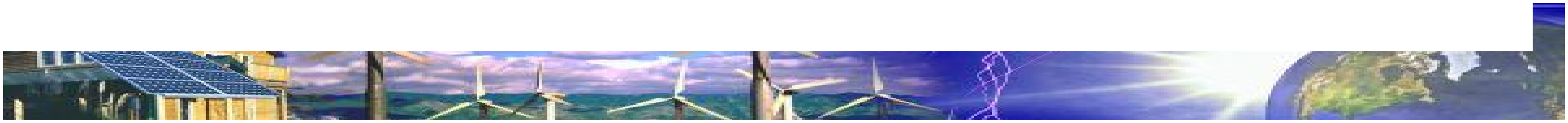
Refrigeration and Air conditioning
Techniques Engineering Department

Subject : Renewable Energy
Grade: 4th Class

Lecture:12 Industrial Process Heat, Chemistry Applications, and Solar Dryers

Dr. Eng. Azher M.Abed

E-email : azhermuhson@gmail.com



Industrial Process Heat

The most important industrial processes using heat at a mean temperature level are sterilizing (التعقيم), pasteurizing(البسترة) , drying(التجيفيف) , hydrolyzing التحلل بالماء, distillationالتقطير and evaporation التبخر, washing and cleaning, and polymerization البلمرة.

General design considerations

Large-scale solar applications for process heat benefit from the effect of scale. Therefore, the investment costs should be comparatively low, even if the costs for the collector are higher. One way to ensure economical terms is to design systems with no heat storage, i.e., the solar heat is fed directly into a suitable process (fuel saver). In this case, the maximum rate at which the solar energy system delivers energy must not be appreciably larger than the rate at which the process uses energy. This system, however, cannot be cost effective in cases where heat is needed at the early or late hours of the day or at nighttime, when the industry operates on a double-shift basis.

The usual types of industries that use most of the energy are the food industry and the manufacture of non-metallic mineral products. Particular types of food industries that can employ solar process heat are the milk (dairies) and cooked pork meats (sausage, salami, etc.) industries and breweries. Most of the process heat is used the food and textile industries for such diverse applications as drying, cooking, cleaning, and extraction.

Solar industrial air and water systems

The two types of applications employing solar air collectors are the open circuit and the recirculating applications. In the open circuit, heated ambient air is used in industrial applications where, because of contaminants, recirculation of air is not possible. Examples are paint spraying, drying, and supplying fresh air to hospitals.

A solar energy system may deliver energy to the load either in series or parallel with the auxiliary heater. In a series arrangement, shown in **Figure 5.1**, energy is used to pre-heat the load heat transfer fluid, which may be heated more, if necessary, by the auxiliary heater, to reach the required temperature. If the temperature of the fluid in the storage tank is higher than that required by the load, a three way valve, also called a tempering valve, is used to mix it with cooler make-up or returning fluid. The parallel configuration is shown in **Figure 5.2**. Since the energy cannot be delivered to the load at a temperature lower than that of the load temperature, the solar system must be able to produce the required temperature before energy can be delivered.

Solar industrial air and water systems

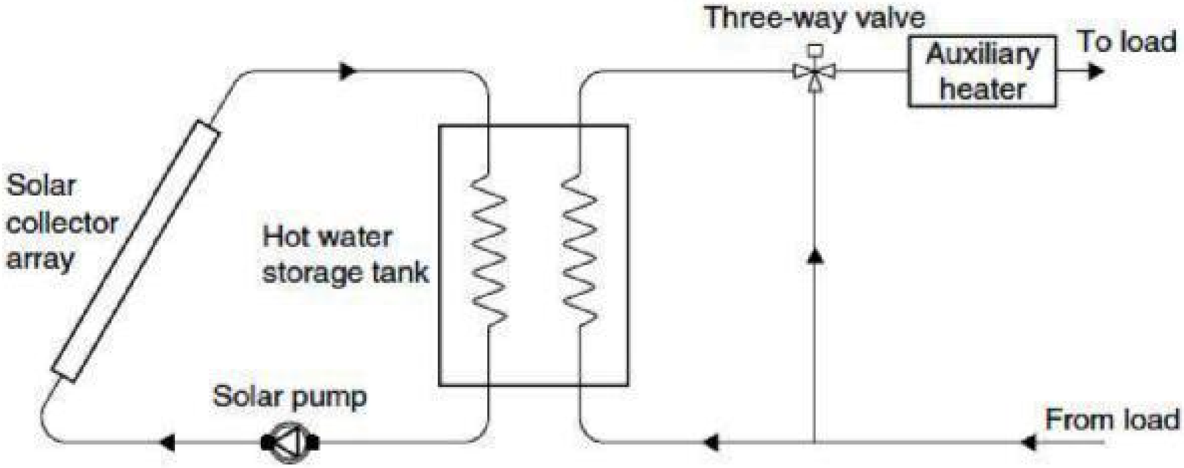


Figure 5.1 Simple industrial process heat system with a series configuration of auxiliary heater

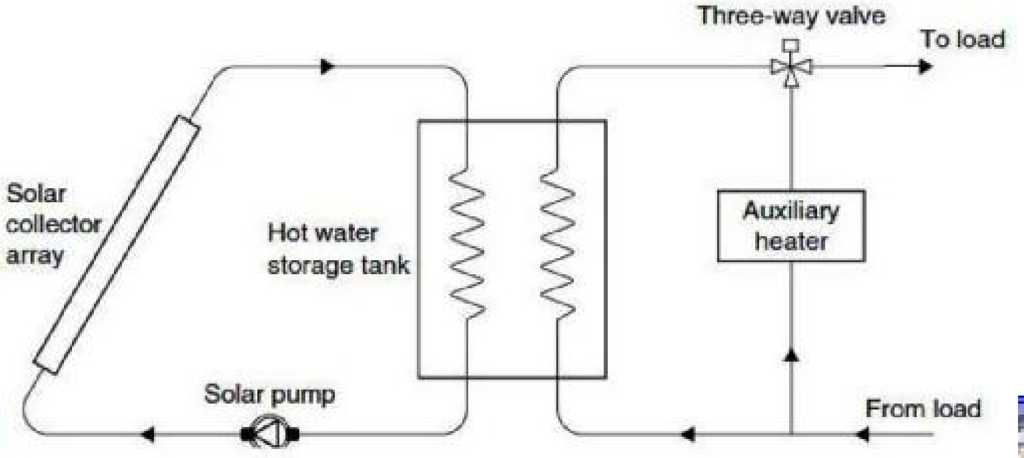


Figure 5.2 Simple industrial process heat system with a parallel configuration of auxiliary heater.

Solar industrial air and water systems

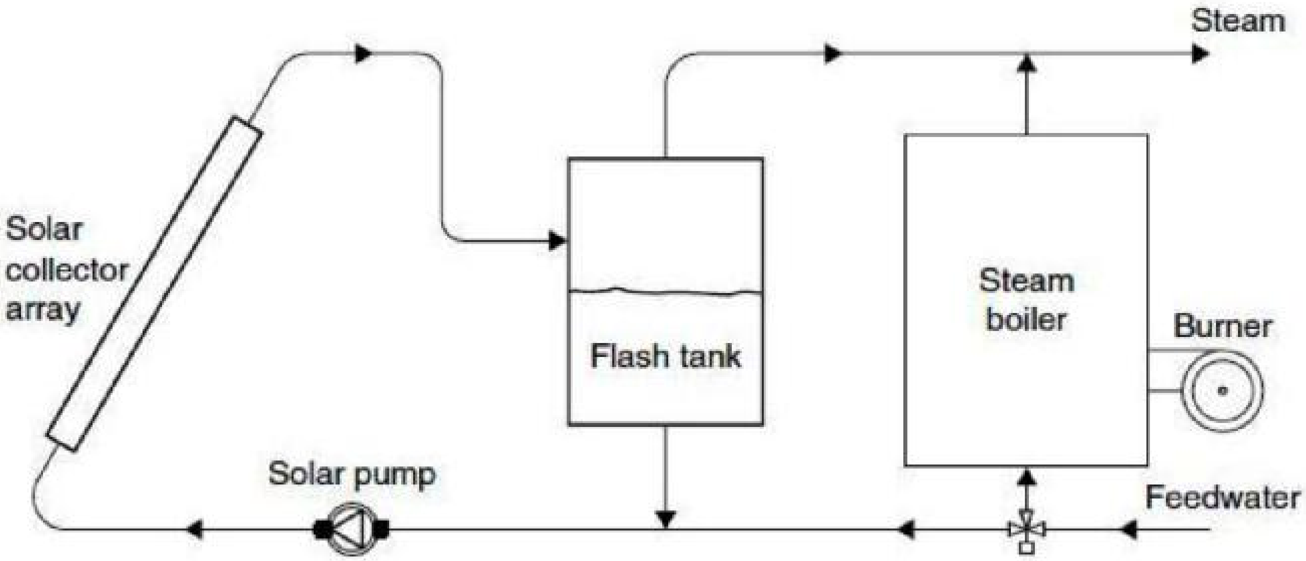


Figure 5.3 Simple industrial process heat steam system with a parallel configuration with an auxiliary steam boiler

Solar steam generation systems

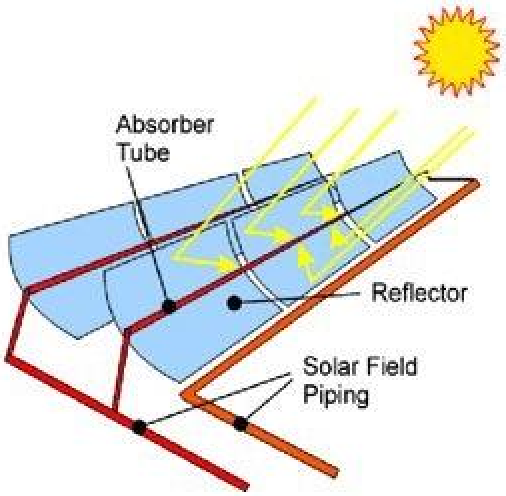
Parabolic trough collectors are frequently employed for solar steam generation because relatively high temperatures can be obtained without serious degradation in the collector efficiency. Low-temperature steam can be used in industrial applications, in sterilization, and for powering desalination evaporators.

Three methods have been employed to generate steam using parabolic trough collectors:

1. The steam-flash concept, in which pressurized water is heated in the collector and flashed to steam in a separate vessel.
2. The direct or in situ concept, in which two-phase flow is allowed in the collector receiver so that steam is generated directly.
3. The unfired boiler concept, in which a heat transfer fluid is circulated through the collector and steam is generated via heat exchange in an unfired boiler.

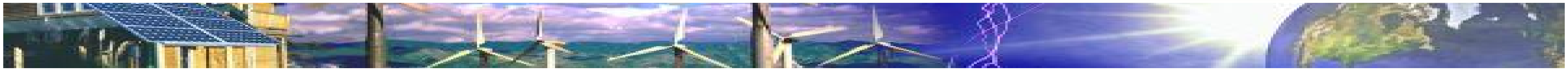
Solar steam generation systems

"Solar Thermal Power Plant" محطات الطاقة الشمسية الحرارية



"Parabolic Trough" تقنية مرايا القطع المكافئ

تستخدم الطاقة الشمسية لإنتاج الطاقة الكهربية ففي أمريكا توجد بعض المحطات التي تعتمد علي تقنية مرايا القطع المكافئ "Parabolic Trough" في تركيز أشعة الشمس علي ماسورة توجد أعلي مركز القطع الناقص لترتفع درجة حرارة الماء لأعلي من درجة الغليان ليتحول بعد ذلك إلي بخار يوجه إلي توربينة ومن ثم توليد الكهرباء.



Steam Generation Methods

The steam-flash system is shown schematically in **Figure 5.4**. In this system, water, pressurized to prevent boiling, is circulated through the collector and flashed across a throttling valve into a flash vessel. Treated feedwater input maintains the level in the flash vessel and the sub cooled liquid is recirculated through the collector.

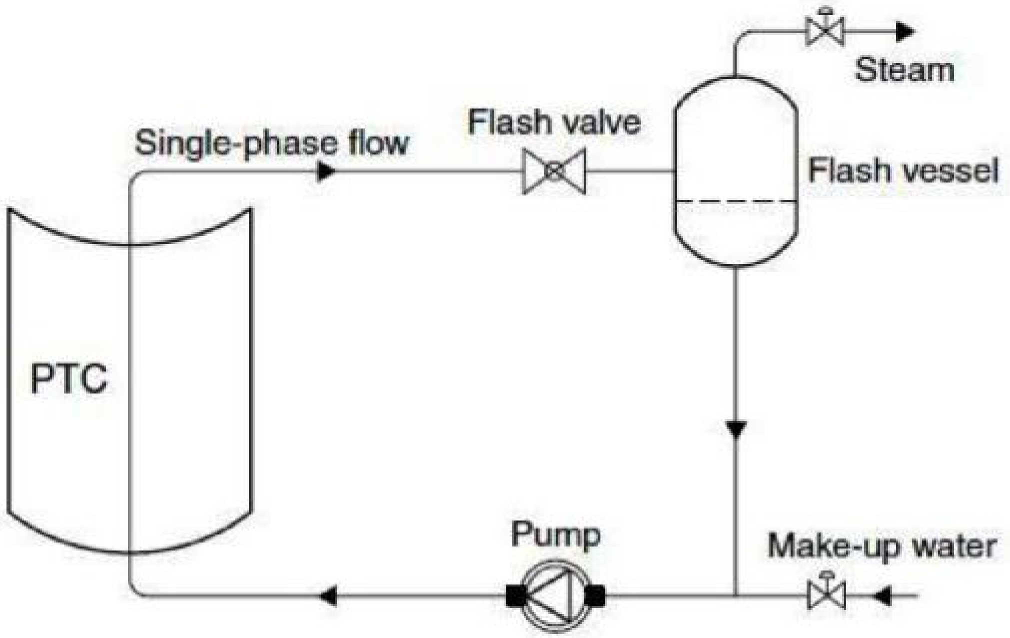


Figure 5.4 The steam-flash steam generation concept

Steam Generation Methods

The in situ boiling concept, shown in **Figure 5.5**, uses a similar system configuration with no flash valve. Sub cooled water is heated to boiling and steam forms directly in the receiver tube. capital costs associated with direct steam and flashsteam systems are approximately the same.

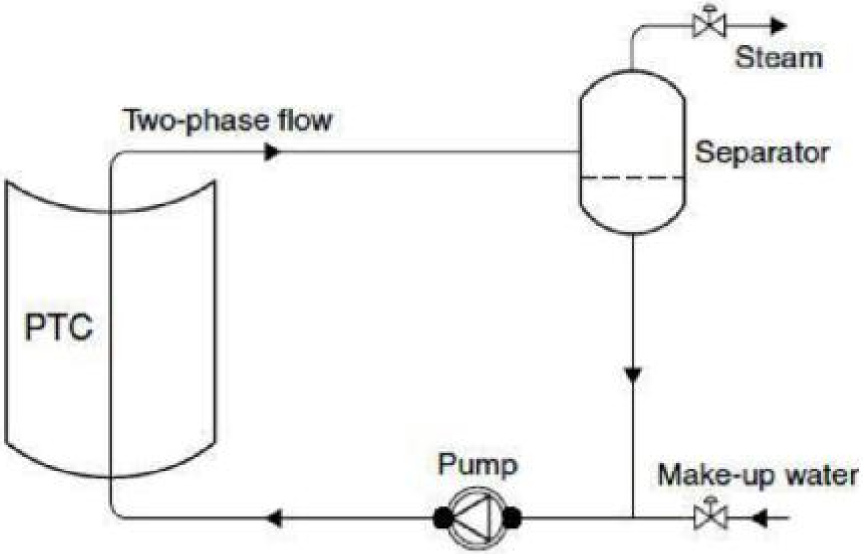


Figure 5.5 The direct steam generation concept.

Steam Generation Methods

A diagram of an unfired boiler system is shown in **Figure 5.6**. In this system, a heat transfer fluid is circulated through the collector, which is non-freezing and noncorrosive and in which system pressures are low and control is straightforward. These factors largely overcome the disadvantages of water systems and are the main reasons for the predominant use of heat transfer oil systems in current industrial steamgenerating solar systems

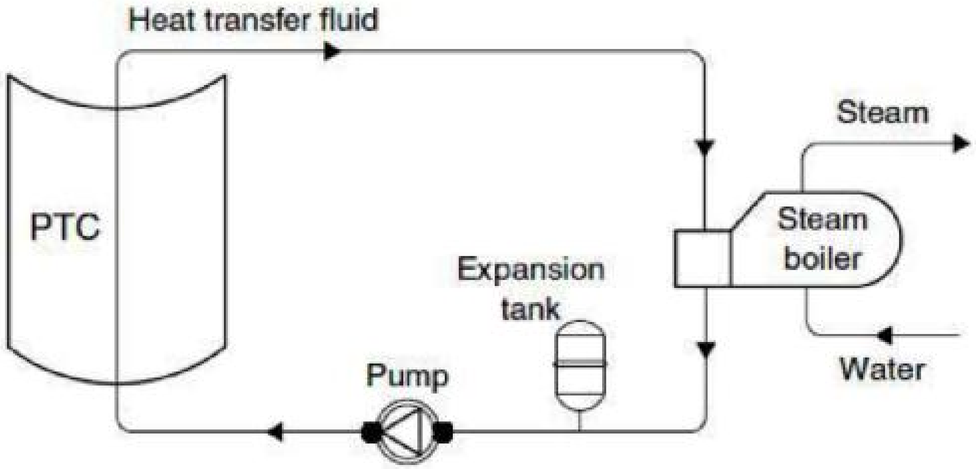


Figure 5.6 The unfired boiler steam generation concept

Sizing of the sub-Systems

The factors that determine the size of the various subsystems are:

- the rate of steam consumption at the user's location in kg/h
- the temperature of the steam in °C
- the duration of the above requirements in a day.

Collector Field

Two pieces of information are required before sizing the collector field. (a) the daily average direct solar radiation at the place of interest and (b) the all-day efficiency of the collector field modules.

Sizing of the Subsystems

Having obtained the above two information's, the sizing of the collector field is carried out in the following way:

-Let the temperature of the pressurized hot water at the outlet of the collector field be To (°C).

- Let the corresponding pressure be Po kg/cm^2.
- The heat required to produce 1 kg of saturated steam is

$$h_g = h_f + xL$$

where

hg = specific enthalpy of saturated vapor in kcal/kg
hf = specific enthalpy of saturated liquid in kcal/kg
L = latent heat in kcal/kg
x = dryness fraction.

Sizing of the Subsystems

From steam tables, corresponding to To °C, the values of hf and L can be obtained. If Ti is the initial temperature of the cold water, then the corresponding value of available heat will be hf1

Therefore, the heat required to produce 1 kg of steam is : $Q_s = (h_g - h_{f1})$ kcal.

The heat required to produce m_s kg/h of steam is: $Q_s = Q_s \times m_s$ kcal/h.

If the plant operates for 8 h, then the total heat required for 8 h duration is:

$$Q_T = \frac{8Q_s}{860} \text{ kWh.}$$

Sizing of the Subsystems

Let the aperture area of each line focus concentrator by Aa,. Let the daily average of direct solar energy falling on a square meter of collector (8 h duration) be I_{Da}). Let the efficiency of the collector module be η_{c}. Then, the area of the collector field required is

$$A_{\mathrm{a}} = \frac{Q_{\mathrm{T}}}{I_{\mathrm{Da}}\,\eta_{\mathrm{c}}}\,\mathrm{m}^2.$$

Heat Balance for The Steam Generation

Let the steam temperature required at the user's location be Ts °C.
Let the corresponding steam pressure be Ps kg/cm^2 (abs).
Let the required flow rate of steam be m_s kg/h.

Enthalpy of water at P_s kg/cm^2 (abs) $= h_{fa}$ kcal/kg

Enthalpy of steam at P_s kg/cm^2 (abs) $= h_{ga}$ kcal/kg

Let the pressure of water from the collector field at the inlet to the flash boiler be P_1 kg/cm^2 (abs). Let the temperature of the saturated water at this pressure be Tsw °C. Let the required flow rate of feed water be m_{fw} kg/h, which is needed to generate steam at m_s kg/hr. Assume Tsc °C of subcooling. Then, the temperature of water at the inlet to the flash boiler is

$$T_{sw} - T_{SC} = T_1 \text{°C}$$

Enthalpy of saturated water at P_1(abs) $= h_{fs}$ kcal/kg

Enthalpy of water at T_1°C and P_1 kg/cm^2(abs) $= h_{f1}$ kcal/kg.

Heat Balance for The Steam Generation

Let the flow rate of water through the collector field be X kg/h. Let the ambient temperature be T_a °C. Then, the heat content of feed water + heat of water from solar collector = heat content of water at inlet to circulating pump + heat content of main steam [quantity of feed water from solar collector = quantity of water at the inlet to the circulating pump = X kg/h].

$$m_{fw}h_{fa} + Xh_{f1} = Xh_{fs} + m_s h_{ga}$$

$$X = \frac{(m_s h_{ga} - m_{fw}h_{fa})}{(h_{fs} - h_{f1})}\ \text{kg/h.}$$

Thus, the flow of water through the solar collector field can be obtained from the heat balance equation.

Flash Vessel Design

To separate steam at lower pressure, a flash vessel is used. This is a vertical vessel, as shown in **Figure 5.7,** with the inlet of high-pressure, high-temperature water located at about one third of the way up its height

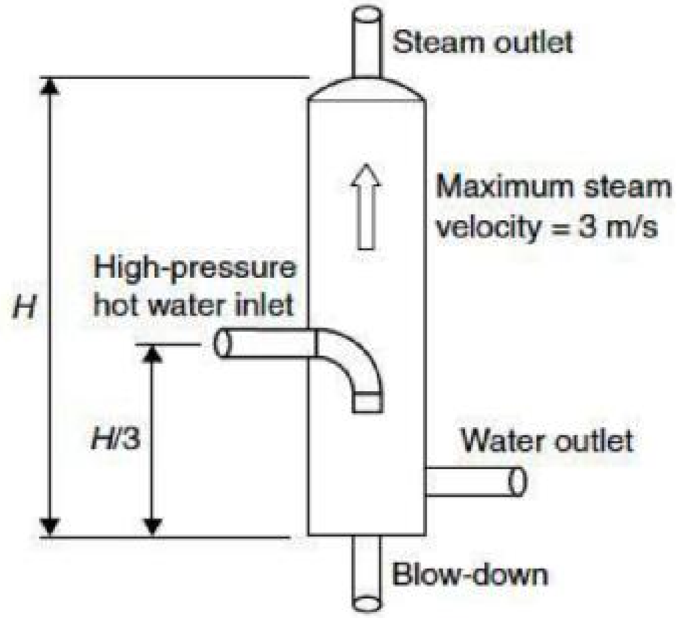


Figure 5.7 Flash vessel schematic diagram

to calculate the percentage flashing in flash vessel: the percentage flash steam generated

$$= \frac{\text{difference in sensible heat}}{\text{latent heat of steam at vessel pressure}}$$

$$= \frac{h_{f(T_W - T_{SC})} - h_{f(T_S)}}{h_{g(T_S)}} \times 100$$

$$= F\%.$$

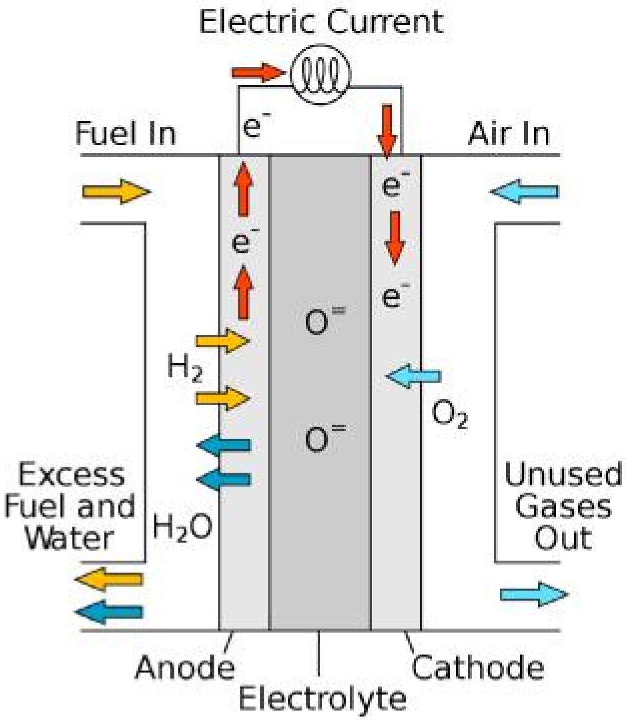
Let the steam generation be m_s kg/h.
Let the steam pressure be P_S kg/cm^2 (g).
Let the corresponding steam temperature be T_S °C.
Let the working pressure of the collector field be P_W kg/cm^2.
Let the working temperature of the collector field be T_W °C.
Assume a subcooling temperature of T_{SC} °C.

From steam tables, the following values, viz. h_f at $(T_W - T_{SC})$, h_f at T_S and h_g at T_S can be obtained.

5.3 Solar chemistry applications

Solar chemistry applications include a variety of fields; the main ones are the production of energy carriers (e.g., hydrogen), also called *reforming of fuels*; fuel cells; materials processing

There are four main sources for the commercial production of hydrogen: natural gas, oil, coal, and electrolysis; which account for 48%, 30% 18% and 4% of the world's hydrogen production respectively. Fossil fuels are the dominant source of industrial hydrogen. Carbon dioxide can be separated from natural gas with a 60-70% efficiency for hydrogen production and from other hydrocarbons to varying degrees of efficiency.[Specifically, bulk hydrogen is usually produced by the steam reforming of methane or natural gas. The production of hydrogen from natural gas is the cheapest source of hydrogen currently. This process consists of heating the gas in the presence of steam and a nickel catalyst.



5.4 Solar dryers

Solar drying is another very important application of solar energy. Solar dryers use air collectors to collect solar energy. Solar dryers are used primarily by the agricultural industry. The purpose of drying an agricultural product is to reduce its moisture content to a level that prevents its deterioration. In drying, two processes take place: One is a heat transfer to the product using energy from the heating source, and the other is a mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air.

5.4.1 Active Solar Energy Dryers

Distributed type

A typical distributed-type active solar dryer is shown in **Figure 5.8**. It comprises four components: a drying chamber, a solar energy air heater, a fan, and ducting to transfer the hot air from the collector to the dryer.

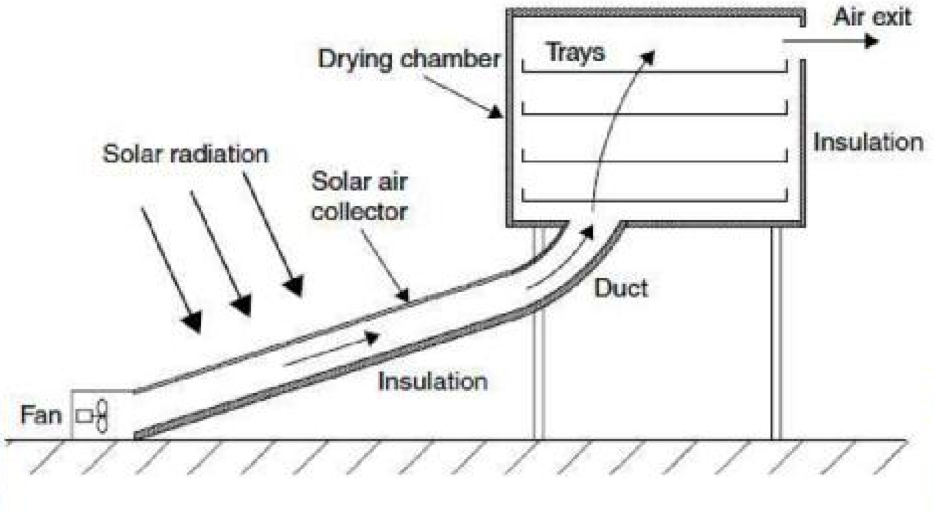


Figure 5.8 Schematic diagram of a distributed-type active solar dryer.

5.4 Solar dryers

Integral type

Large-scale, commercial, forced-convection, greenhouse-type dryers are like transparent roof solar barns and are used for solar timber drying kilns (أفران تجفيف الأخشاب الشمسية)**(see Figure 5.9).** Small-scale forced dryers are often equipped with auxiliary heating. Another variation of this type of dryer is the solar collector–roof/wall, in which the solar heat collector forms an integral part of the roof and/or wall of the drying chamber.

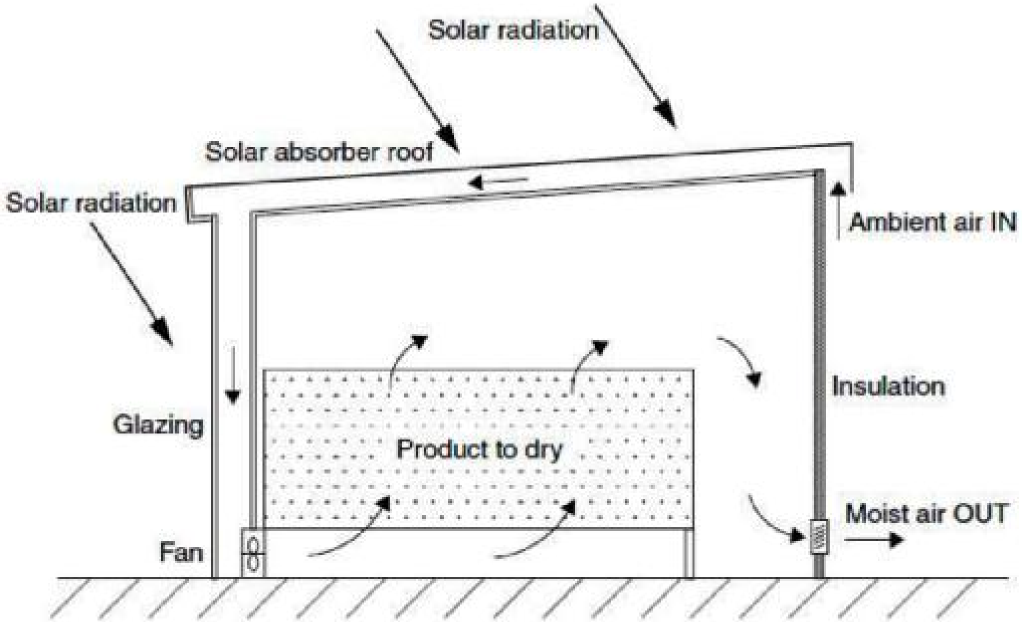


Figure 5.9 Schematic diagram of a forced-convection, transparent-roof solar barn.

5.4 Solar dryers

A solar-roof dryer is shown in **Figure 5.10**. A collector-wall system is like a Trombe wall, where a black painted concrete block wall with outside glazing forms the solar collector and serves also as a thermal storage.

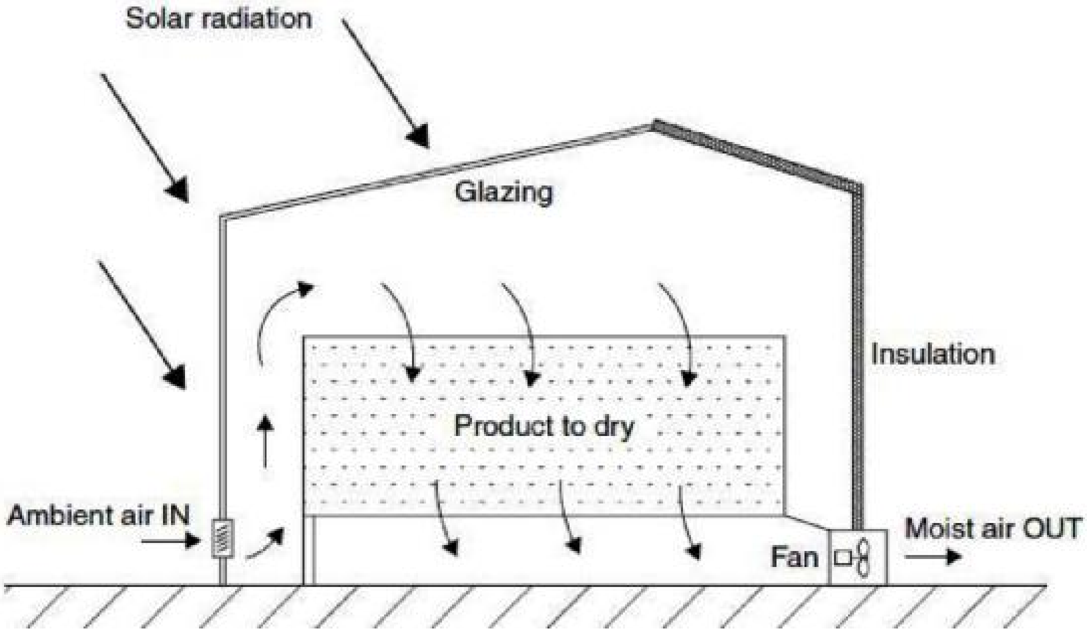


Figure 5.10 Schematic diagram of an active collector–roof solar energy storage dryer.

5.4 Solar dryers

Mixed-mode type

The mixed-mode dryer is similar to the distributed type with the difference that the walls and roof of the dryer are made from glass, to allow solar energy to warm the products directly, as shown in **Figure 5.11**.

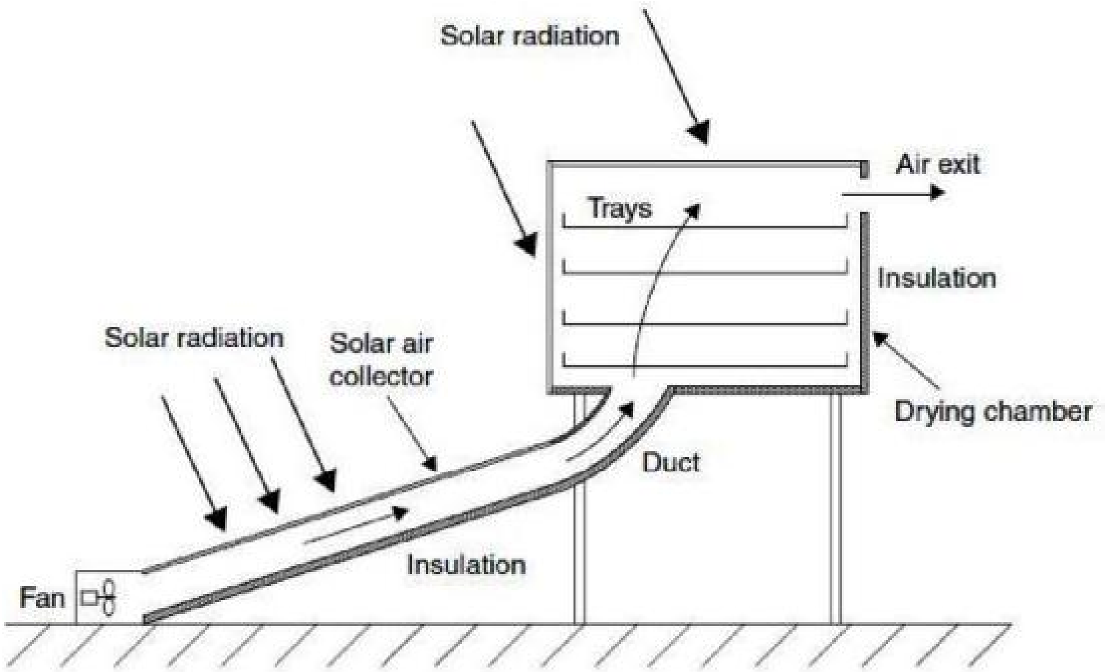


Figure 5.11 Schematic diagram of a mixed-mode-type active solar dryer

5.4 Solar dryers

5.4.2 Passive Solar Energy Dryers

Passive or natural circulation solar energy dryers operate by using entirely renewable sources of energy, such as solar and wind.

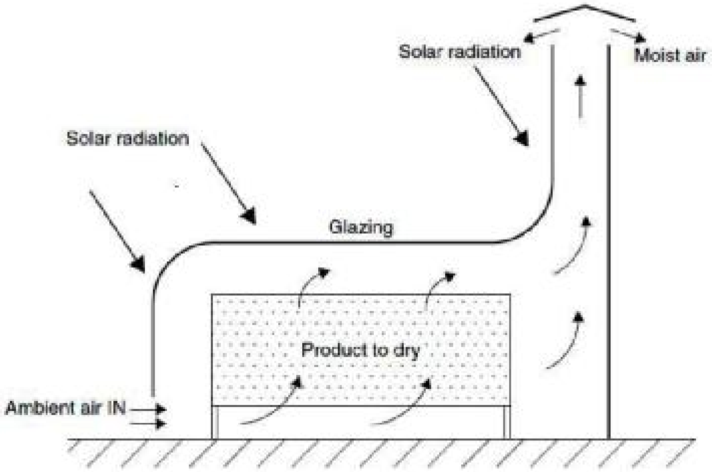


Figure 5.13 Schematic diagram of an integraltype passive solar dryer

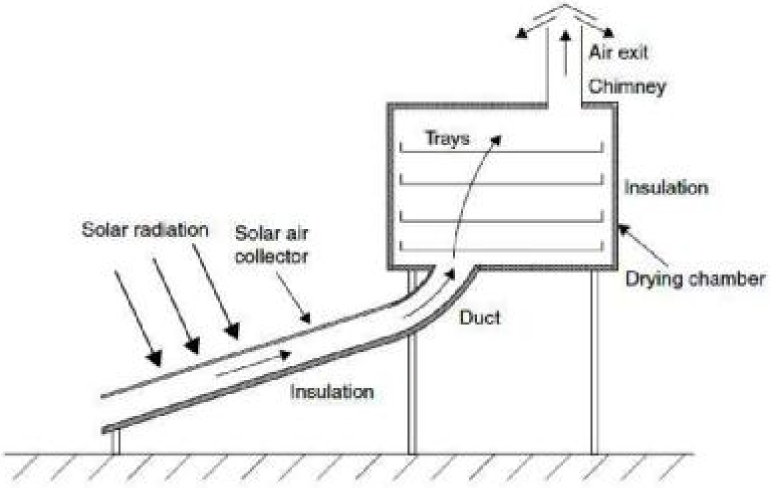
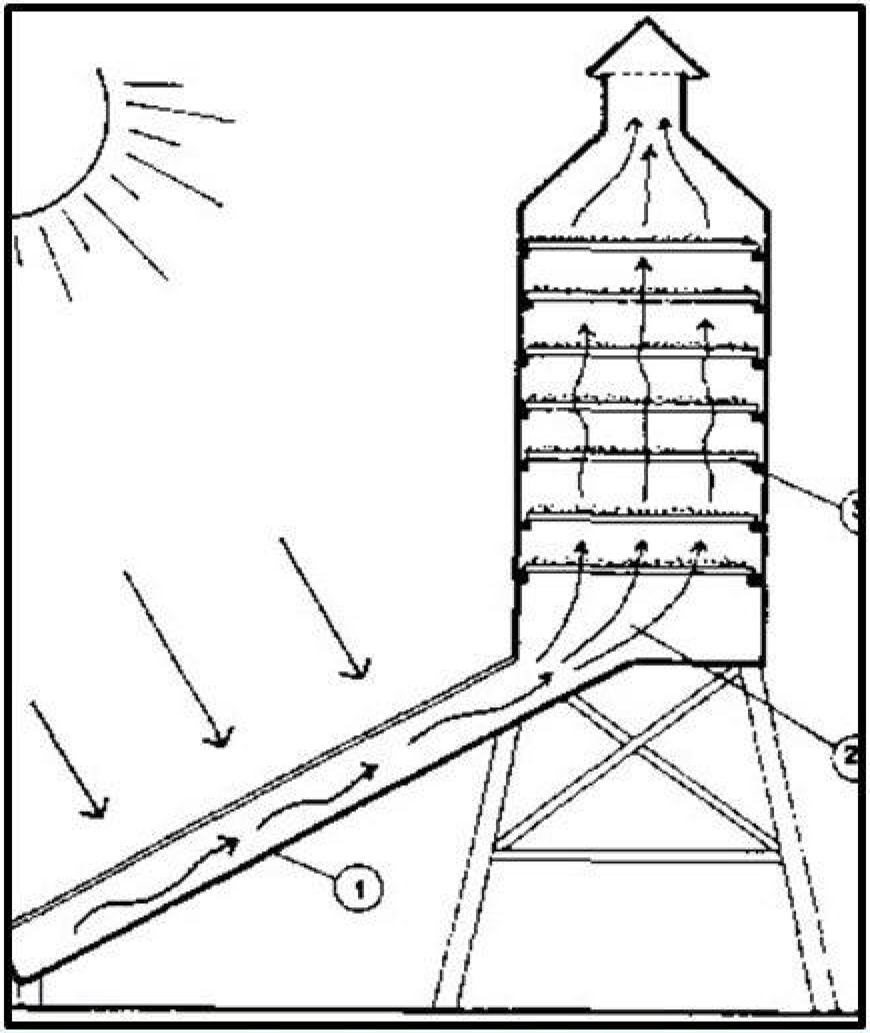


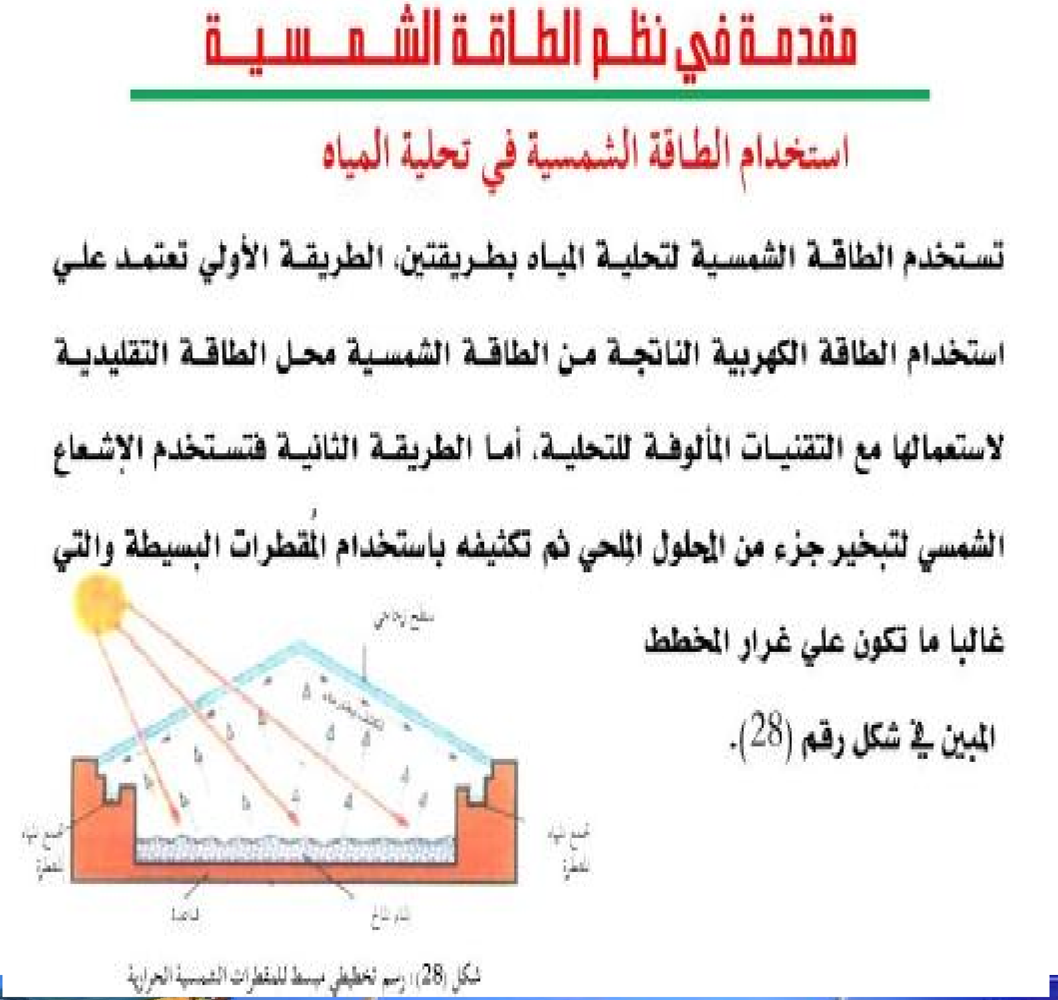
Figure 5.12 Schematic diagram of a distributedtype passive solar dryer.

5.4 Solar dryers

تجفيف المحاصيل الزراعية



6.3 Direct collection systems



مقدمة في نظم الطاقة الشمسية

استخدام الطاقة الشمسية في تحلية المياه

تستخدم الطاقة الشمسية لتحلية المياه بطريقتين، الطريقة الأولي تعتمد علي استخدام الطاقة الكهربية الناتجة من الطاقة الشمسية محل الطاقة التقليدية لاستعمالها مع التقنيات المألوفة للتحلية، أما الطريقة الثانية فتستخدم الإشعاع الشمسي لتبخير جزء من المحلول الملحي ثم تكثيفه باستخدام المُقطرات البسيطة والتي غالبا ما تكون علي غرار المخطط المبين في شكل رقم (28).

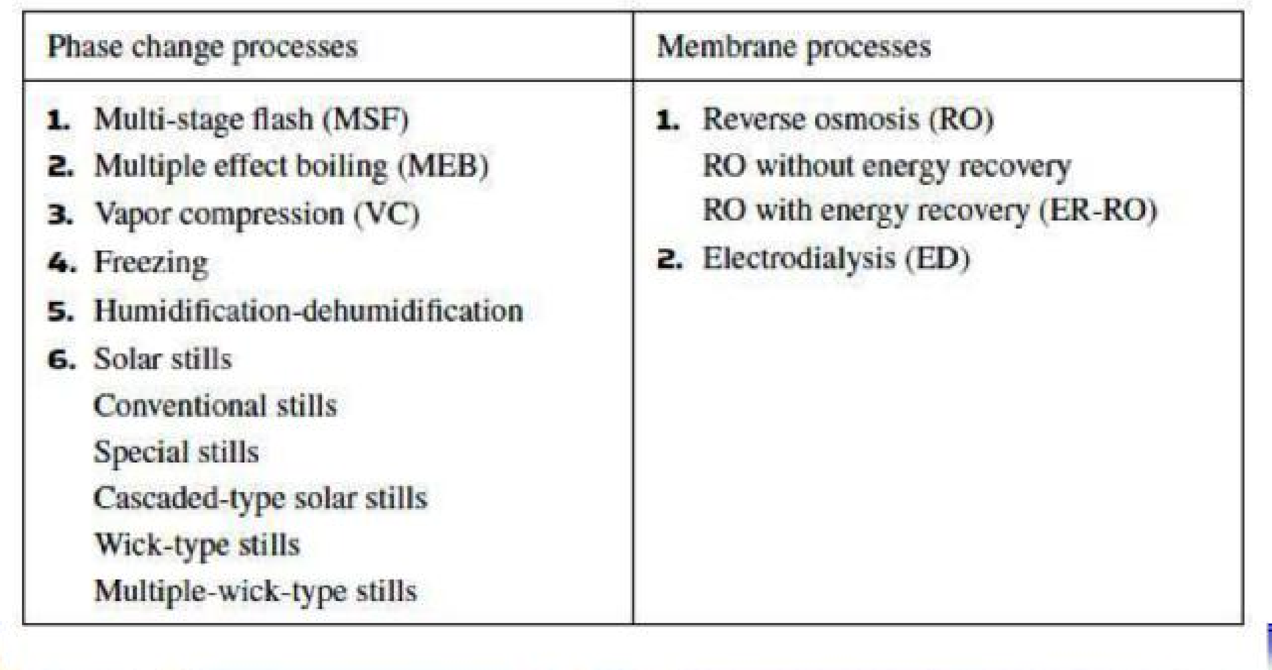
شكل (28) رسم تخطيطي مبسط للمقطرات الشمسية الحرارية

6. Solar Desalination Systems

The provision of freshwater is becoming an increasingly important issue in many areas of the world. In arid areas, potable water is very scarce and the establishment of a human habitat in these areas strongly depends on how such water can be made available.

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.

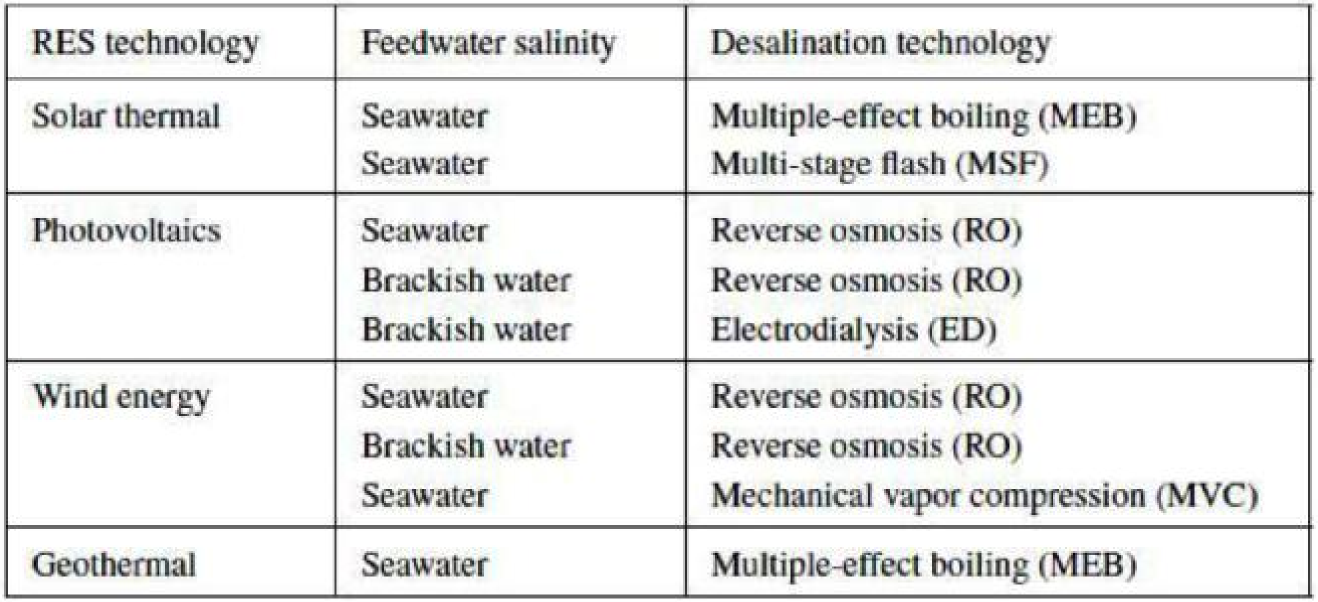
6.1 Desalination processes In **Table 6.1**, the most important technologies in use are listed



Phase change processes	Membrane processes
1. Multi-stage flash (MSF) 2. Multiple effect boiling (MEB) 3. Vapor compression (VC) 4. Freezing 5. Humidification-dehumidification 6. Solar stills Conventional stills Special stills Cascaded-type solar stills Wick-type stills Multiple-wick-type stills	1. Reverse osmosis (RO) RO without energy recovery RO with energy recovery (ER-RO) 2. Electrodialysis (ED)

6. Solar Desalination Systems

Table 6.2 Renewable Energy System Desalination Combinations



RES technology	Feedwater salinity	Desalination technology
Solar thermal	Seawater Seawater	Multiple-effect boiling (MEB) Multi-stage flash (MSF)
Photovoltaics	Seawater Brackish water Brackish water	Reverse osmosis (RO) Reverse osmosis (RO) Electrodialysis (ED)
Wind energy	Seawater Brackish water Seawater	Reverse osmosis (RO) Reverse osmosis (RO) Mechanical vapor compression (MVC)
Geothermal	Seawater	Multiple-effect boiling (MEB)

6.3 Direct collection systems

Among the non-conventional methods to desalinate brackish water or seawater is solar distillation. this process requires a comparatively simple technology and can be operated by unskilled workers. Also, due to the low maintenance requirement, it can be used anywhere with a smaller number of problems.

A representative example of the direct collection system is the typical solar still, which uses the greenhouse effect to evaporate salty water. It consists of a basin in which a constant amount of seawater is enclosed in an inverted V-shaped glass envelope **(see Figure 5.14).** The sun's rays pass though the glass roof and are absorbed by the blackened bottom of the basin.

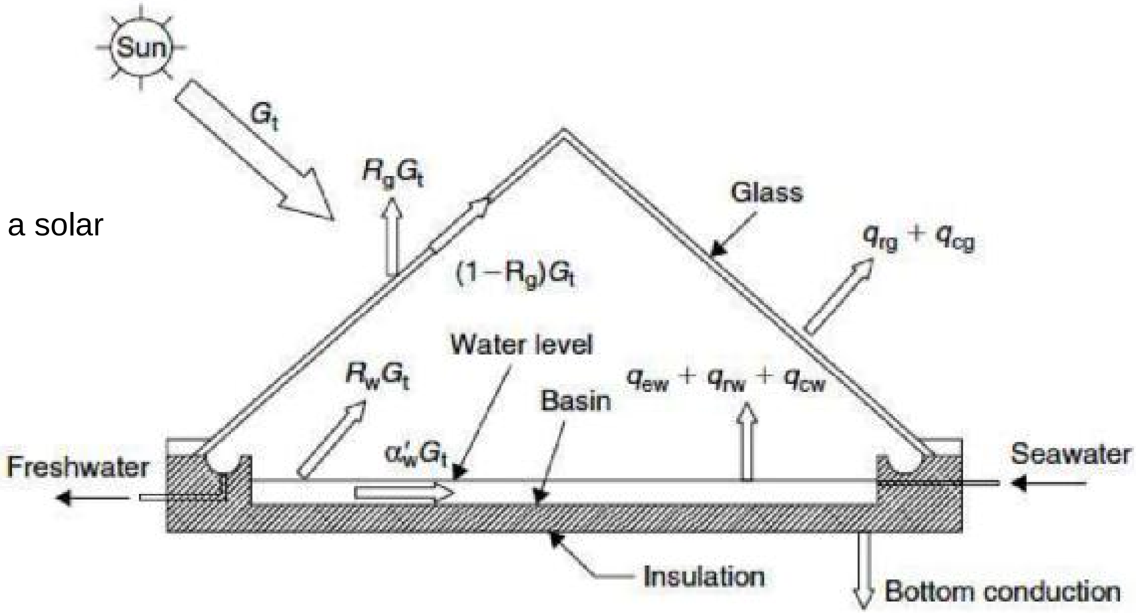


Figure 5.14
Schematic of a solar still.

Performance of Solar Stills

$$\eta = \frac{q_{ew}}{G_t} = \frac{h_{cw}(t_w - t_g)}{G_t}$$

6.3 Direct collection systems

A flat plate collector is integrated with the solar still, to increase the temperature of the basin water.

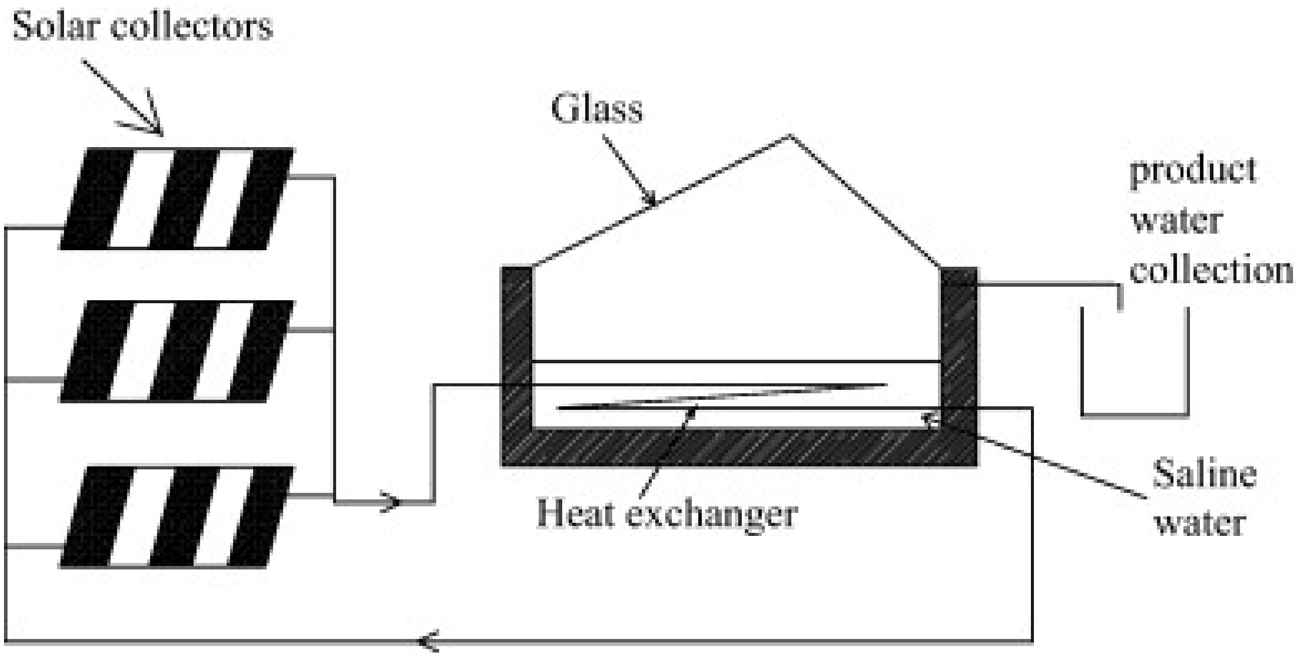


Figure 5.1 5 Schematic of a solar still with flat plate collector .

6.4 Mini solar pond

Integrated a mini solar pond with single basin solar still as shown in Fig. 5.16. The mini solar pond supplied hot water to the solar still. Thus evaporation rate of the saline water in the solar still was augmented. The productivity of the solar still increases by 27.6% than the conventional solar still.

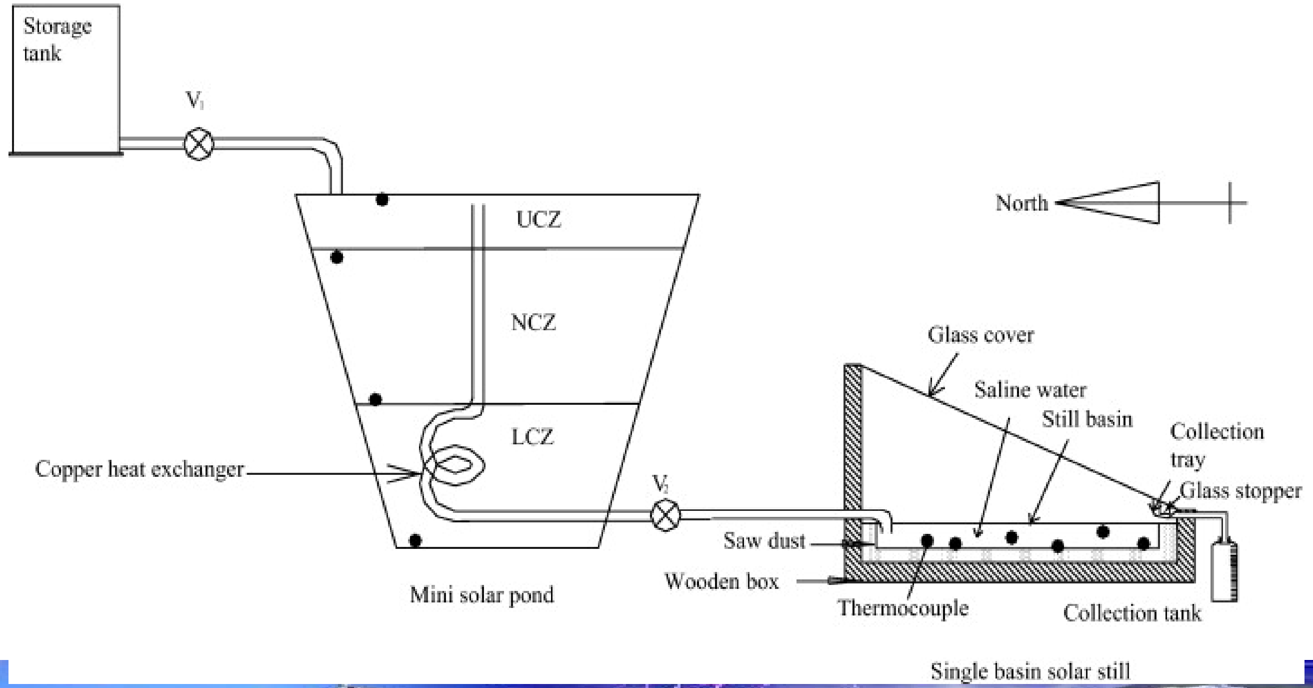


Figure 5.16 Schematic of a Solar still integrated with a mini solar pond.

Do You Have Any Questions?