CHAPTER 2

LITERATURE REVIEW

In this chapter, work on solar distillation, its present status in the world today and its future perspective are briefly discussed. The review also includes historical background, status of solar distillation in India, and effect of various parameters on productivity. The classification of distillation units has been done on the basis of literature survey till today. Special attention is given to the passive solar distillation system with design modifications to improve the yield, as they are the main objective of this present study.

2.1 HISTORICAL BACKGROUND OF SOLAR DISTILLATION

Distillation has long been considered a way of making salt water drinkable and purifying water in remote locations. As early as the fourth century B.C., Aristotle described a method to evaporate impure water and then condense it for potable use. Arabian alchemists were the earliest known people to use solar distillation to produce potable water in the sixteenth century. However, the first documented reference for a device was made in 1742 by Nicolo Ghezzi of Italy, although it is not known whether he went beyond the conceptual stage and actually built it. The first modern solar still was built in Las Salinas, Chile, in 1872, by Charles Wilson (Hay, 1973). It consisted of 64 water basins (a total of 4,459 square meters) made of blackened wood with sloping glass covers. This installation was used to supply water (20,000 liters per day) to animals working in mining operations. After this area was opened to the outside by railroad, the installation was
allowed to deteriorate but was still in operation as late as 1912-40 years after its initial construction. This design has formed the basis for the majority of stills built since that time. During the 1950s, interest in solar distillation was revived, and in virtually all cases, the objective was to develop large centralized distillation plants.

In California, the goal was to develop plants capable of producing one million gallons, or 3,775 cubic meters of water per day. However, after about 10 years, researchers around the world concluded that large solar distillation plants were too expensive to compete with fuel-fired ones. Therefore, research shifted to smaller solar distillation plants. Between 1960 and 1970, 38 plants were built in 14 countries, with capacities ranging from a few hundred liters to around 30,000 liters of water per day. Of these, about one third have since been dismantled or abandoned due to material failures. None in this size range is reported to have been built in the last 7 years.

Despite the growing discouragement over community-size plants, McCracken Solar Company in California continued its efforts to market solar stills for residential use. Worldwide interest in small residential-units is growing, and now that the price of oil is ten times what it was in the 1960s, interest in the larger units may be revived.

2.2 CLASSIFICATION OF SOLAR STILL

Solar distillation systems (solar stills) are classified broadly into two categories: passive and active solar stills as shown in Figure 2.1. Passive systems are those in which solar energy is collected by the structure elements (basin liner) for evaporation of saline water. Various types of passive solar stills are described in the literature like conventional solar still, vertical solar stills, plastic solar stills, cascade type solar stills, multi wick solar still, multi effect or multi stage solar still, multi basin solar still, greenhouse type solar still, spherical solar still etc. In the case of active solar still, an additional thermal energy by external mode is required for faster evaporation. The extra
Solar stills

Passive solar stills

- Basin
  - Single
    - (Based on slope)
  - Double

- Wick type
  - Single
    - (Based on of basin)
  - Multiple

- Others

Active solar stills

- Integrated with
  - Collecting system

- Waste heat recovery

- Solar heater

- Solar concentrator

Figure 2.1 Classifications of solar distillation system
energy may be obtained from a flat plate solar collector, additional condenser, inverted absorber. The classification of these development techniques are addressed and summarized below.

### 2.2.1 Passive Solar Stills

The simple basin type passive solar still, which is used most widely, is shown schematically in Figures 2.2 and 2.3.

![Image](image1.png)

**Figure 2.2 Single slope single basin solar still (Tiwari and Tiwari 2006)**

![Image](image2.png)

**Figure 2.3 Double slope single basin solar still (Tiwari 2003)**
The conventional passive solar still is the most economical solar still to provide drinking water for domestic applications at decentralized level. This is due to the fact that it is simple in design and fabrication, easy to handle (unskilled manpower is sufficient) along with longer life, and low cost of water per litre. Further, due to low operation and maintenance cost it is most suitable in rural areas of remote region. The active solar still is more suitable for commercial applications like distilled water for selling purposes, extraction of essence from different seeds and green leaves etc., use in batteries, chemical laboratories etc (Tiwari et al 2003).

### 2.2.2 Multi Basin Solar Stills

The thermal efficiency of a solar distillation unit in terms of daily production per square meter can be increased by the utilization of the latent heat of condensation. The reutilization of latent heat in two or more basins is generally known as a multi basin solar still. A schematic of a double basin double slope solar still is shown in Figure 2.4. In a double basin solar still, another glass sheet is fixed in between the basin liner and the glass cover. This glass sheet serves as the base of an extra basin for the saline water, and the whole assembly behaves as two simple basin solar stills placed one above the other. The water in the upper basin makes use of the upward heat loss from the water in the lower basin.

![Figure 2.4 Schematic of a double slope-double basin solar still (Ashokkumar et al 1991)](image-url)
Gupta et al (1988) studied the effect of waste hot water into the lower basin at a constant rate during off sunshine hours. The results show that, the yield increases with flow rate if the inlet waste hot water temperature is above its optimum value and the yield decreases with an increase of water mass in the lower basin. Ashokkumar et al (1991) observed that, the double basin double slope solar still gives better performance than the single basin still due to better utilization of latent heat of vaporization. Dutt et al (1993) studied the effect of water flowing over the glass cover in the double basin solar still. The authors concluded that the flow of water over the glass cover enhances the still productivity and also flowing water at a very low rate increases the distillate output.

2.2.3 Wick Type Solar Stills

A conventional basin type solar stills has some disadvantages, (i) the horizontal surface of water intercepts lower solar radiation than a tilted surface and (ii) the output of basin type solar is also limited by the large thermal capacity of the water in the basin. A multi wick solar still (Figure 2.5) is one alternative for eliminating the above mentioned disadvantages, in which blackened wet jute cloth forms the liquid surface which can be oriented to intercept maximum solar radiation and a smaller mass of water will be heated to higher temperature and will evaporate rapidly. The wet surface is created by a series of jute cloth pieces of increasing length separated by thin polythene sheets, the pieces arranged along an incline with the upper edges are dipped in a saline water tank. Suction by the capillary action of the cloth fiber provides a surface of the liquid and the arrangement ensures that all the surface, irradiated by the sun is wet at all times, the portion of a piece of cloth covered by the polythene sheet does not suffer evaporation and hence the exposed portion of the piece retains wetness (Sodha et al 1981).
Sodha et al (1981) observed that the overall efficiency of multiple wick solar still is 4% higher than the basin type still. Their results also show that the still costs less than half of the cost of a basin type still of the same area and provides a higher yield of distillate. Tiwari and Garg (1984) also confirmed that the multiple wick solar still is the most economical and efficient among the existing solar stills. Reddy et al (1983) showed that a multiple solar still with a condenser arrangement gives 15 – 25% higher than the non condenser type still. The excess vapor can be condensed on the additional surface and reduce the heat loads on the glass cover and reduces glass cover temperature which in turn enhances evaporation rate. This concept has been implemented by Tiwari and Selim (1984) on multi wick solar still. The authors concluded that the double condensing, multiple wicks solar still gives nearly 20% higher yield than the simple wick solar still. Under that cloudy and low intensity conditions both stills show almost a similar performance. Dhiman and Tiwari (1990) indicated that the multiple wick solar still yield increased by 10% when water is flowing over the glass cover in a very thin layer.

Yeh and Chen (1986) investigated the effects of climatic, design and operational parameters on the output of wick type solar stills. Abu-Hijleh and Rababa’h (2003) have proposed modifications to enhance the distillate
production by placing the sponge cubes over the water surface. The sponge cubes increased the surface area over which evaporation of water occurs, and caused the increase in output by 18%. Akash et al (1998) have studied the effect of using different absorbing materials like black rubber mat, black dye and black ink to enhance the still output by 30–40%. Tiwari et al (1984) have studied the performance of a double condensing multiple-wick solar still. In this still, the area of the condensing surface had been increased by introducing an additional galvanized iron sheet just below the blackened wet jute cloth. Frick and Sommerfeld (1973) proposed a wick-type solar still, in which blackened wet jute cloth formed the liquid surface, which could be oriented to intercept maximum solar radiation and attain a high temperature on account of low thermal capacity.

2.2.4 Other Types of Passive Solar Stills

2.2.4.1 Tubular solar still

The tubular solar still design consists of a rectangular black metallic tray placed at the diametric plane of a cylindrical glass tube. The length and diameter of the glass tube are slightly greater than the length and width of the tray, respectively. During operation, the ends of the glass tube are sealed with gasketed wooden heads. The tray and glass tube are fixed slightly tilted from the horizontal plane but in opposite directions. Brine fed from one end is partly evaporated, and the remainder discharged through the other end of the tube. The evaporated water condensed on the inside walls of the glass cover flows down and is removed from one end at the bottom of the glass tube (Figure 2.6). The feed brine flow rate may be controlled by varying the location of the overflow hole of the flow control tank (Tiwari and Ashokkumar 1988).
Figure 2.6 Schematic representation of a tubular solar still (Tiwari 1988)

Tiwari and Ashokkumar (1988) studied the performance of a tubular solar still for nocturnal production based on the effect of brine flow, still length, initial brine temperature and other climatic conditions. Based on the analysis, they concluded that, (i) the average brine temperature is independent of still length for higher flow rate while the output temperature of brine strongly depends on still length and (ii) the daily yield of distillate in the tubular solar still is higher than that of the conventional solar still.

2.2.4.2 Spherical solar still

The spherical solar still (Figure 2.7) consists of a blackened metallic plate placed horizontally at the centre of a transparent envelope, which is spherical in shape and is usually made of glass. Dhiman (1988) presented a mathematical model to predict the thermal performance of a spherical solar still. The results show that efficiency of spherical solar still 30% more than that of the conventional solar still.
2.2.4.3 Solar still integrated with greenhouse

A schematic diagram of a solar still-cum greenhouse, indicating the absorption of solar energy by the roof and wall is shown in Figure 2.8. The absorbed solar radiation by the basin liner is partially transferred to water mass, and the rest is transferred to a room by conduction, convection and radiation. The stored energy in the water causes evaporation, and it then condenses and ultimately comes out in the form of fresh water to be used for irrigation purposes. The remaining transmitted solar energy is absorbed by the plants and the floor, after reflection. The absorbed energy is transferred to enclosed air by convection and radiation from the plant and floor; hence, air in the room is heated. A part of the energy absorbed by the floor is also conducted into the ground. If crops can be grown in strong sunlight without the debilitating effects of high temperatures, then high crop yields can be achieved with a significantly reduced consumption of water.
Srivastava et al. (2000) presented the performance evaluation of distillation cum greenhouse for a warm and humid climatic condition. Their result shows that, there is a marginal difference between the values of plant and room temperature, water, transparent cover and also basin liner temperatures. Distillate output can be used in irrigation and greenhouse will provide the desired temperature to the plant in a warm and humid climate in coastal regions. Sodha et al. (1980) conducted experimental studies on roof type solar still and concluded that, in summer, the daily heat flux in the room gets reduced by 40% and in winter, mixed with black dye to obtain water, the daily heat flux in the room increased by a factor of two, thereby increasing productivity.
2.2.4.4 Plastic solar still

Phadatare and Verma (2007) conducted an experimental study on the effect of water depth on the internal heat and mass transfer in a single basin single slope plastic solar still (Figure 2.9). The plastic still was fabricated from Plexiglas. Based on experimental results, the authors concluded that, (i) the maximum distillated output of 2.1 lit / m² / day was obtained with a water depth in a 2 cm still basin and (ii) the maximum efficiency of the experimental stills varies from 10% to 34%. It was found that the efficiency is maximum for a water depth of 12 cm.

![Figure 2.9 Schematic of a plastic solar still (Phadatare and Verma 2007)](image)

2.2.4.5 FRP solar stills

The cross sectional view of the single slope Fibre Reinforced Plastic (FRP) solar still is shown in Figure 2.10. A novel feature in this type of still is the absence of insulation on the sides and bottom. The advantages of the FRP stills are long life expectancy of at least 10 years, easy to handle and absence of any kind of insulation.
Figure 2.10 Cross-sectional view of single slope FRP still (Tiwari et al 1986)

Tiwari et al (1986) and Yadav and Tiwari (1987), from their experimental study, concluded that, in winter the single slope FRP still gives better yield than the double slope stills and that in summer the double slope stills give better yield than the single slope still. Tiwari and Mohamed selim (1984) showed that, a double slope FRP multi wick solar still is more economical and efficient than a simple one. Singh and Tiwari (1992) have studied a double effect multi wick solar still with water flow into the basin. The results show that, (i) double effect distillation is more efficient for the low flow velocity required in the wick solar still and (ii) overall thermal efficiency decreases with an increase of mass flow rate.

2.2.4.6 Inverted absorber solar still

The schematic diagram of inverted absorber solar still is shown in Figure 2.11. The solar radiation, after transmission through the glass cover g1, is reflected back to the inverted absorber of a solar still. The absorbed solar radiation is partially convected to the water mass above the inverted absorber, while the rest of the radiation is lost to the atmosphere through the glass
covers g1 and g2 and the water gets heated up. There are radiative, convective and evaporative heat losses from the water mass to the condensing cover. The evaporated water is condensed on the inner surface of the condensing cover, releasing its latent heat. The condensed water trickles down the condensing surface under gravity and is finally collected through drainage provided at the lower end.

Tiwari and Suneja (1998, 1999) presented an analysis of an inverted absorber solar still. Their results show that the inverted absorber solar still gives about double the output of the conventional solar still. Also the authors observed that, the evaporative heat loss is a strong function of the operating temperature. Suneja et al (1997) also observed that, an inverted absorber solar still gives a higher output than the conventional double effect solar still. The overall daily yield in the case of the inverted triple effect absorber solar still is 30% higher than the conventional triple effect solar still (Suneja and Tiwari 1999).

Figure 2.11 Schematic diagram of inverted absorber solar still (Tiwari and Suneja 1998)
Suneja and Tiwari (1998) found that, (i) the yield from inverted absorber solar stills increases as the number of basins increased and reaches an optimum value when the number of basin is seven, (ii) the operation and maintenance expenses of inverted double basin solar still are small compared to the conventional solar system.

2.2.4.7 Vertical solar still

A schematic diagram of the unit of distillation is shown in Figure 2.12. It is mainly composed of, head tank to feed brackish water, vertical solar still and metallic support.

![Figure 2.12 Schematic diagram of the vertical solar still (Boukar and Harmim 2004)](image)

The operating process is as follow: The brackish water (1) enters the head tank (2), the head tank is connected to the vertical solar still (4), and the flow rate of brackish water is regularised by a valve (3). In a vertical solar still, brine passes through a horizontal PVC distributor that is equipped with small holes, and brine falls downwards by gravity on the spongy absorbing surface (5). Finally it reaches the bottom and drains out through a copper tube (6). The distilled water is collected in a test tube (8).
Boukar and Harmim (2004) tested on a vertical solar still to study parametric values affecting the performance of the still under desert climatic conditions: effects of saline water input and output temperature to the still, ambient temperature, cover glass temperature, solar radiation and orientation of the still and productivity of still. It is concluded that the productivity of the vertical still strongly depended on solar radiation, ambient temperature and solar orientation.

2.2.4.8 Cascade still

Schematic diagrams of the ordinary cascade still and the modified one are shown in Figure 2.13. Galvanized iron sheets of 1 mm thick were used in fabricating the metallic trays of the still's basin and a metal trough for collecting the distillate. An insulating layer of polyurethane, 4 cm thick was located beneath the metallic basin. The metallic basin with the insulation beneath it was contained in a wooden frame. The condensation unit was a metallic box having the dimensions of 100 × 100 × 1 cm, over which the vapor condensed. The condensation unit acted as a preheater for the brine feed to the evaporation unit. Between the evaporation and condensation units, there were two 0.1 H.P. fans to suck the humid air from the evaporation unit and transfer it to the condensation unit. Saline water was stored in a 1 m³ tank manufactured from 1 mm thick galvanized iron, and lined with bitumen. The saline water flows through plastic tubes (to prevent corrosion) to the metallic box in the condensation unit to increase its temperature. The surface temperature of the box was always high due to the condensation of vapor over it. Hot saline water was then fed through an upper opening in the evaporating unit and cascaded down from one tray to another through an opening adjusted to keep a constant level of water in each tray. Overflowing brine could be discarded through an overflow tube located in the last tray. Distilled water, condensing on both the condenser reservoir and underside of the glass cover, was collected in a measuring cylinder (El-Bassuoni 1986)
Figure 2.13 Cross-section of the ordinary cascade still (El-Bassuoni 1986)

(1) Overflow pipe (2) Fresh water trough (3) Wooden Frame
(4) Insulation (5) Metallic Basin (6) Transparent Cover
(7) Feeding Pipe

Headley (1973) developed a new design for a tilted double-sided solar still with cascade water trays made of corrugated aluminium which are positioned 3.2 cm below the glass cover on insulated supports. He obtained the thermal efficiency of 60% - 75% due to the short distillation gap, the high condensing ratio, the low thermal inertia, and the fact that most heat transfer from the cascade to the condensing surfaces is accompanied by vapour transfer since radiative and conductive heat losses from the cascade are small.

2.2.4.9 Parabolic still

A schematic diagram for the experimental set-up of parabolic solar still is given in Figure 2.14. The apparatus consists of mainly a parabolic concentrator, separation and condensation unit, and two heat exchangers. In the separation and condensation unit, the steam coming may be combined with hot water through point 5 and condensed on the surfaces of the two inclined plates inside the unit. Then it is collected to flow through point 8.
Meanwhile, the non-distilled water comes out from point 7. The upper inclined plate has a gap near its lower end, which allows the condensed water to fall down on the lower plate. The separation and condensation unit is fabricated from galvanized steel. In the first heat exchanger, the raw water makes use of the sensible heat contained in the condensed steam. The water that exits from the first heat exchanger (point 3) enters the second heat exchanger, in which the raw water temperature increases once again due to the sensible heat contained in the non-distilled water. It is to be pointed out that the elevation level of the separation and condensation unit must be higher than the top of the heat exchangers, which means that the elevations of points 6 and 7 must be higher than those of points 3 and 10.

Figure 2.14 Parabolic solar still (El-Kassaby 1991)

El-Kassaby (1991) studied a complete design and fabrication for a distilled water apparatus using a line concentrator of parabolic reflector type, which can be used for sea water distillation. A steady state theoretical model based on energy balance is presented. The experimental results are compared
with the theoretical ones as well as with the available data, and a satisfactory agreement is shown.

2.2.4.10 Staircase still

The experimental equipment of staircase solar still (Barrera, 1992) is presented in Figure 2.15. Important features to be appreciated are the separating screens, whose function is to retain variable amounts of water, in particular the water to be distilled, in such a plane angle as to receive the highest direct solar radiation incident. Due to the similarity of the arrangement of the screens in the still to that of a stairway, this unit is called as a stair way solar still. It can also be observed from Figure 2.17 that the lateral walls of the distillator are inclined, which helps to avoid shadowing effects common in stills with 90° vertical walls. Due to the configuration and inclination of the apparatus the condensation area is 1.8 times larger than the evaporation area, which allows the increase of the temperature gradient between the bottom and the top of the still, and thus leads to a significant increase in distillate production as compared to the production obtained with other designs.

Figure 2.15 Diagram of staircase solar still (Barrera 1992)
2.2.4.11 Floating vertical solar still

A schematic diagram of the experimental set-up of the floating vertical solar still is shown in Figure 2.16.

![Schematic diagram of the floating vertical solar still](image)

**Figure 2.16 Schematic diagram of the floating vertical solar still (Minasian and Al-Karaghoul 1992)**

The still consisted of a vertical conical shaped blackened cotton wick (representing absorbing/evaporating surface) having good capillarity. The conical wick was installed inside an identical transparent glass cover (4 mm thick) with suitable annular space. The diameter of the conical wick was 90 cm and its height was 45 cm, the conical glass cover was 100 cm in diameter and 50 cm high. Each of the two conicals inclined at an angle of 45° to the horizontal. The top of the conical glass cover was left open to include an end plug used for periodic cleaning of salt deposits which may have accumulated at the upper part of the conical wick. The base section of the conical cover was properly designed to allow the bottom of the wick to soak directly inside the brackish water. The distilled water was collected by a small drainage pipe fixed at the bottom of the still. To keep the vertical still floating inside a metallic pan, the still was set on a sheet of polystyrene. All joints and openings in the top and bottom of the still were well sealed with silicone rubber sealant to ensure no vapor leakage. Collected data included ambient air
temperature, glass cover temperature, blackened wick temperature, temperature of air-water vapor mixture within the still, brackish water temperature inside the pan, global solar radiation, wind speed and distillate output.

Minasian and Al-Karaghouli (1992) investigated the performance of a floating conical solar still used for producing drinking water in brackish marsh areas. Multiple linear regression equations, relating global solar radiation, ambient air temperature, and wind speed with the productivity of the still, have been developed. The regression analysis showed that the daily global solar radiation can be adopted alone to predict still productivity with acceptable accuracy. Results also showed that there is good competition between the proposed conical still and the conventional basin type solar still concerning productivity and operation requirements. Recommendations have been made to use this type of still for ensuring fresh drinking water in marsh areas where the natural supply of fresh water is inadequate.

2.2.4.12 Spray evaporation solar still

A cross section of the spray evaporation still is shown in Figure 2.17.

Figure 2.17 Spray evaporation solar still (Joyce et al 1994)
The device consists of two concentric cylindrical chambers that communicate on the top and bottom. The heated solution is introduced on the top of the inner chamber (the evaporation chamber) by a nozzle that sprays the solution in small drops that increase the surface of evaporation and humidifies the air due to which free convection circulates through the top to the outer chamber (the condensation chamber) where it condenses around a helical pipe producing the distilled water.

Joyce et al (1994) showed from their experimental study on the spray evaporation solar still that productions near 2 kg/h were obtained for temperatures of the hot source of the order of 65 °C and (ii) drop diameters play an important role on the production and conversion rate.

2.3 FACTORS INFLUENCING THE PERFORMANCE OF THE STILL

2.3.1 Water Capacity and Inclusion of Dyes

It is a well known fact that the distillate output decreases significantly with the increase in water depth of the solar still. Many researchers have investigated the effects of climatic, operational and design parameters on the performance of a basin type solar still to improve the output. Malik et al (1982) have reviewed the work on solar distillation that includes various designs of solar stills, like single basin still, multiple effect still, inclined solar stills, solar still greenhouse and effect of meteorological and still parameters, etc. In their studies, it is concluded that there is a variation of 30% in daily yield for variation in depth from 12.7 mm to 305 mm. Effect of heat capacity of basin water on the output of solar stills was investigated by many authors (Lawrence et al 1990, Yadav and Prasad 1995) and they have concluded that the output decreases with an increase in water depth. Further, in a previous work, it has been found that the overnight output
of single basin solar still increases with an increase in the basin water depth and it represents a great part of the daily output of solar stills (Okeke et al 1990, El-Bassuoni 1986). However, a detailed study on the effect of heat capacity of basin water on the solar still performance is still of considerable interest due to some difficulties associated with experimental measurements of the still output overnight (Aboul-Enein et al 1998).

On the basis of year round performance of solar still under Indian climatic conditions, Garg and Mann (1976) concluded that, (i) A lower glass cover angle gives higher output, (ii) for high altitude stations the long axis of the conventional double sloped still should face an east-west direction in order to receive more solar radiation, (iii) A single sloped solar still receives more radiation than a double sloped solar still at low and high altitude stations and (iv) the productivity of a still increases with the decrease in water depth increasing the absorptivity of water by using dyes and increasing initial water temperature by using preheated water.

Tiwari and Madhuri (1987) studied the effect of initial water temperature on the distillation output, and they found that, the yield increases when the initial water temperature of the brine was greater than 45°C. Tripathi and Tiwari (2004) indicated that, the change in the length of a solar still for given height and width of the solar still does not affect the daily output but the change in the height of the north wall for a given height of the solar still affects the daily output. Tiwari and Tiwari (2006) found that the evaporative heat transfer depends significantly on water depths and the nocturnal distillation is significant in the case of higher water depths.

Akash et al (1998) studied the effect of using different absorbing materials in a solar still, to enhance the productivity of water. Experimental results show that using an absorbing black rubber mat increased the daily water productivity by 38%. Using black ink increased it by 45%. Black dye
was the best absorbing material used in terms of water productivity. It resulted in an enhancement of yield to about 60% higher than the conventional still. Rajvanshi (1981) states that the black napthylamine dye is the most suitable dye among all other dyes.

### 2.3.2 Cooling of Condensing Cover and Water Flow in the Basin

The productivity of the still is mainly dependent on the temperature difference between water and condensing cover. The higher this difference the more will be the output. This can be achieved by either increasing the basin water temperature or decreasing the cover temperature or both. These techniques are summarized below. Tiwari and Bapeshwara Rao (1984) studied the effect of cool water flowing over the glass (Figure 2.18) and its velocity. The result shows that, when water flows over the glass cover at a uniform velocity, the daily distillate production of the system is almost doubled.

![Figure 2.18 Schematic representation of the single basin solar still with water flowing over the glass (Tiwari and Bapeshwara Rao 1984)](image)

Lawrance and Tiwari (1990) indicated from their results, that the effect of water flow over the glass cover has a significant effect when heat
capacity of water mass in the basin is higher. Yadav and Ashokkumar (1991) studied the performance of a single basin solar still with water flow in the basin. The authors found that, the water temperature, distillate output and efficiency of the system increases with decreasing mass flow rate and the optimum value of the mass flow rate through the basin of the still is 0.00027 kg/m²s. Abu-Hijleh (1996) concluded that, (i) by the proper combination of cooling film parameters, the still efficiency can be enhanced by as much as six percentage points. On the other hand, a poor choice of the parameters would result in a reduction in still efficiency, (ii) The best combination of cooling film parameters was: film thickness of 2.5 x 10⁻⁴ m, cool water volumetric flow rate per unit width of 5 x 10⁻⁷ m³/s, and glass cover length of 2 m, (iii) The cooling still efficiency increased monotonously with increasing insolation and ambient temperature and (iv) The efficiency of a film cooling still was not sensitive to the wind speed.

Sodha et al (1981) conducted an experimental study of solar still with waste hot water from thermal power plants and their results show that, the still fed with hot water at constant rate gives higher yield in comparison to a still with hot water filled only once in a day. Tiwari et al (1985) concluded from their detailed analysis that, (i) the flow of waste hot water during off-sunshine hours will have higher yield than the stationary water, (ii) the yield increases in proportion to the increase in inlet water temperature during the flow of water, (iii) the still productivity increases with the increase in mass flow rate for higher inlet water temperatures and decreases for inlet water temperature less than the average ambient temperature and (iv) the still productivity is better for the waste hot water flow during off-sunshine hours than the continuous flow of hot water for lower inlet water temperature.
2.3.3 Effect of Condensing Chambers

Tiwari et al (1997) conducted an experimental analysis of a new design of double condensing chamber single basin single slope solar still (Figure 2.19).

![Cross sectional view of a double condensing chamber solar still (Tiwari et al 1997)](image)

The authors concluded that, (i) significant enhancement in daily output was obtained due to a maximum vapor pressure difference between the two condensing chamber on a clear day and (ii) the performance of double condenser chamber solar still gives a higher daily output of about 35% - 77% over the conventional solar still.

2.3.4 Solar Still with Internal Heat Exchanger

Basin water temperature is one of the parameters in increasing the productivity of the still. By providing heat exchanger inside then still and flowing waste hot water from various power plants, industries etc, through the heat exchanger, it is possible to increase the basin water temperature.
Ashokkumar and Tiwari (1990) studied the effect of inlet temperature of waste hot fluid, temperature dependence of internal heat transfer in a double slope single basin solar still with heat exchanger (Figure 2.20). The results show that, the internal evaporative heat transfer is a strong function of the initial water temperature of the waste hot water.

2.3.5 Solar Still with Absorbing Medium

Some materials can store more amount of heat energy and increase the heat capacity of the basin in addition to increasing the basin absorption. Black rubber, gravels and aluminum sheet are some of the materials having these properties. Valsaraj (2002) conducted an experimental study of single basin still with floating absorber aluminum sheet over the water surface. The result indicated that, the floating absorber sheet improves the output of the still compared to an ordinary conventional still. Sakthivel and Shanmugasundaram (2008) studied the effect of black granite gravel (Figure 2.21) as a storage medium and found that, the still yield is increased by 17% -20% compared with conventional still. Also the authors given the following points are to be considered while selecting energy storage medium for effective performance of the still.
• Heat capacity of the storage medium should be low so that the temperature rise will be more which will increase the temperature of the saline water.

• The energy storage medium should not reduce the temperature of the saline water in the evaporating zone which will reduce the temperature gradient between water and glass surface.

• Storage medium should have low thermal conductivity to reduce heat loss through the bottom of the still.

• Storage medium should be easily available at a low cost.

Figure 2.21 Sectional view of the solar still with gravel (Sakthivel and Shanmugasundaram 2008)

An attempt has been made by El-Sebaii et al (2000) to decrease the preheating time of the basin water of basin type solar stills. A single slope single basin solar still with baffle suspended absorber (SBSSBA) was designed and fabricated using locally available materials. It was found that the daily productivity of the SBSSBA is about 20% higher than that of the conventional still (SBSS). Nafey et al (2001) used black rubber and black
gravel materials within a single sloped solar still as a storage medium and studied the effect of rubber thickness and gravel size under the same climatic conditions. The results showed that black rubber (10 mm thick) improves the productivity by 20% at the conditions of 60 litre/m$^2$ brine volume and 15° glass cover angle. Also, using black gravels of 20-30 mm size improves the productivity by 19% at the conditions of 20 litre/m$^2$ brine volume and 15° of glass cover angle.

Rahim (2003) proposed an approach for a conventional still to store excess energy during day time that can be used for continuation of evaporation at night. In this work the authors had divided the basin water into evaporating and heat storing zones. They have found that the heat storing capacity of water during day time is about 35% of the total amount of solar energy entering the still. Mona and Mervat (2002) designed a simple solar still with phase change materials like paraffin wax and paraffin oil as the energy storage medium to make use of its latent heat of fusion for storing the excess solar energy at noon. That stored energy was used to evaporate water during evening and night, when solar energy is absent. They achieved an average still output of 2.5 litre/m$^2$ day with 15% improvement in output.

### 2.3.6 Surface Treatment of the Glass Cover

Bahadori and Edlin (1973) studied the effect of surface treatment of glass on the performance of simple solar still. In their experiments, still glazings are treated with sodium silicate or hydrofluoric acid to make them more wettable. Consequently, the angle of inclination can be reduced by 1°-5°. They found that, the treatment of glass glazing with either sodium metasilicate or hydrofluoric acid reduces the permissible glazing slope and increases water production.
2.3.7 Effect of Condensing Surface Area

Tayeb (1992) conducted an experimental study on four different designs of basin-type stills (Figure 2.22) to find the effect of condensation area on the efficiency and performance. The stills have the same area of evaporation but different shapes and thus different areas of condensation. The effects of these design factors as well as the effects of materials of construction and some operating factors such as basin temperature, cover temperature, ambient temperature and solar intensity is examined and analyzed. The results show that a higher ratio of condensation area \((A_c)\) to evaporation area \((A_e)\) leads to a higher productivity, if not contradicted by another effect such as shading.

Figure 2.22 Different designs of passive solar stills (Tayeb 1992)
1- Distilled water out 2- Overflow 3 - Saltwater (brine)
4- Glass cover 5- Thermal insulation 6- Still-wash opening
7- Plexiglas cover(s)
The authors concluded that:

(i) Increasing the area of condensation increases the productivity, but the area occupied is more. This is because of the shading effect of the cover that lowers the productivity.

(ii) Glass as a cover material is more effective than Plexiglas during sunshine hours, but Plexiglas gives better results at or after sunset.

(iii) A higher basin temperature is always associated with a higher productivity, and the reverse is true for cover temperature.

(iv) The shading effect of the cover is minimized at and near solar noon, and this increases the hourly productivity of the still with two concentric covers in this period relative to other periods.

(v) A higher solar intensity corresponds to a higher productivity for different still designs.

2.3.8 The Effect of Back Fins and Crossing Tubes

El-Bassouni (1993) investigated the ordinary basin-type solar still and considered some developments that could be made to improve its performance by increasing the solar radiation penetrating inside the still and increase the rate of vapor condensation.

Five stills of the same dimensions (Figure 2.23) but of different design were erected and tested. The top covers of all five were made of glass. Three side walls of three of these stills were made of glass, and the walls of the other two stills were made of galvanized steel. The effect of substituting galvanized steel by glass is studied. Also, three stills are equipped with a finned galvanized steel back to work as a secondary condensing surface, and its effect on productivity is studied. Besides, two stills were fitted with open glass tubes crossing its sides to help reach the dew point of the vapor inside. The effect of this design is investigated. The authors concluded that,
The productivity of the still increases with the increase in intensity of solar radiation. However, this factor should be studied altogether with other factors such as brine temperature.

The still with glass sides has a higher productivity than a conventional still made of galvanized iron. The effect of glass sides in increasing the productivity is more pronounced in winter than in summer.

Fitting the back side of the still with fins increases the productivity due to increase of the area of condensing surface.

Providing the still with glass tubes crossing its sides increases the productivity.

**Figure 2.23** Schematic drawing of different stills (El-Bassouni 1993)
1. Top cover (glass) trough. 2. Still sides (galvanized steel).
2.3.9 Effect of Wind Velocity

Mohammed Farid and Faik Hamad (1993) studied experimentally the effect of wind velocity on the performance of solar still. In their experiments hourly and daily measurements of the still productivity, temperature of water, glass cover, and ambient air were recorded during both summer and winter seasons. The results show that, the efficiency of the still was independent of solar radiation and increase in diffused radiation lead to slight decrease in its efficiency. It was concluded that, an increase in still productivity occurs with the increase in ambient temperature and decrease in wind velocity. In their experimental studies, and Fath and Elsherbiny (1993) concluded that, (i) the daily total still production increased by decreasing the water depth and increasing insulation thickness, (ii) increasing the wind speed resulted in a relatively small reduction in still productivity and (iii) the maximum production rate occurred when the solar radiation was at the peak and the time lag increased with the increase in water depth.

2.3.10 Effect of Removal of Water Vapour Inside the Still

In a conventional basin type solar still vapour produced from water in the basin condenses on the underside of the glass cover. The latent heat of condensation of water vapour raises the temperature of the glass cover, and is lost to environment. This results in a low temperature difference between the glass cover and water in the basin. Since the rate of evaporation of water from the basin depends on this temperature difference, and on the presence of saturated water vapour in the space between the glass cover and the water surface, yield of distillate from the still is reduced and a low thermal efficiency of the still is obtained. Figure 2.24 shows the cross sectional view of the thermo-electric solar still proposed by Nijegorodov et al (1994).
Figure 2.24 A basin type still with an exhaust fan and a condenser (Nijegorodov et al 1994)

The principle of this still is that saturated water vapour from the site of evaporation is passed through a separate water-cooled condenser, where the latent heat of condensation is used up to pre-heat the water for the still. The glass cover over the basin is placed horizontally against the sloping glass covers in a conventional basin type still. Water vapour produced from the absorption of solar radiation by saline water in the basin is pumped out using a low power exhaust fan and is passed through a water-cooled condenser coil. A 100 W fan per square metre of the basin area is used. The distilled water is collected in a tank connected to the other end of the condenser coil. As the cooling water in the condenser tank heats up, there is evaporation of water inside the condenser tank also. This vapour is condensed on the sloping cover of the condenser tank and drips down a central tube into the distillate collection tank. This provides additional distilled water the quantity of which depends on the temperature of water in the tank above ambient temperature. There is a small loss of water that escapes uncondensed. Its quantity depends
on the water temperature near the bottom of the condenser. This loss can be minimise by optimising the size of the condenser such that the temperature of water near the bottom is as close to ambient as possible. Pre-heated water from the condenser supplies the next batch of re-charge for the still basin. It was observed from their studies that, the yield of distillate from the still is nearly doubled.

2.3.11 Effect of Condensing Cover Slope

Aboul-Enein et al (1998) investigated the thermal performance of the still both experimentally and theoretically based on analytical solution of the energy balance equations for different parts of the still. Their study also included the influence of cover slope on the daily productivity of the still. Effect of heat capacity of basin water during daylight and overnight productivities was also studied. It is inferred that, the productivity of the still decreases with an increase of heat capacity of basin water during daylight and it is the reverse during night. The optimum tilt angles of the still cover were found to be 10° and 50° during the summer and winter seasons respectively.

2.3.12 Sun Tracking System

Abdallah and Badran (2008) studied experimentally the enhancement of solar still productivity by using sun tracking system. A computerized sun tracking device was used for rotating the solar still with the movement of the sun. A comparison between fixed and sun tracked solar stills showed that the use of sun tracking increased the productivity for around 22%, due to the increase of overall efficiency by 2%. It is concluded that, (i) by using the sun tracker the water temperature increases, and the thermal capacity of the water decreases, by which the evaporation rate increases, hence the production will be increased and (ii) the sun tracking is more effective than fixed system and is capable of enhancing the productivity.
2.4 ACTIVE SOLAR DISTILLATION SYSTEMS

The productivity of the solar still also improved through active methods of integrating the still with either a solar heater, solar concentrator or other heating devices. The blackened surface of the flat-plate collector absorbs solar radiation, and the liquid in contact with it gets heated. This heated liquid is circulated through the heat exchanger and it gives its heat to water in the still. The blackened bottom of the still also absorbs solar radiation that heats the water. The evaporation of water in the still starts, and when the air inside the still is saturated, the water vapor condenses on the relatively cooler surface of the glass cover. The water droplets slide down under gravity to the drainage. The circulation of water through the flat plate collector is made possible either using pump (active mode) or by thermosiphon operation (natural circulation mode).

![Schematic diagram of single basin solar still coupled to flat plate collector](image)

*Figure 2.25 Schematic diagram of single basin solar still coupled to flat plate collector (Rai and Tiwari 1983)*
Rai and Tiwari (1983) presented the performance of a single basin solar still coupled with a flat plate collector (Figure 2.25). The results show that, the average daily production of distilled water has been found to be 24% higher than that of a simple single basin solar still. Rai et al (1990) concluded that, the best performance was achieved by the single basin still coupled with a flat plate collector having forced circulation and blackened jute cloth floating over the basin water and a small quantity of black dye added to the water. From the economic point of view, the circulating pump should be used in the morning and evening when thermosiphon stops during sunshine hours.

Yadav (1991) studied the performance of a solar still integrated with a flat plate collector using a thermosiphon mode of operation and compared it with forced circulation mode. The authors concluded that, (i) the system using the forced circulation mode gives 5% - 10% higher yield than that of the thermosiphon mode and (ii) A 30% – 35% enhancement in the yield is observed with the proposed system as compared to the conventional system. Tiwari (1985) concluded that for higher daily yield, the collector should be disconnected from the still during off-sunshine hours. Tiwari and Dhiman (1991) indicated that for drinking purpose, the conventional still will give better performance because the efficiency of the system reduces with an increase in the effective area.

Sanjeevkumar and Tiwari (1988) found that, the optimum collector inclination is 20° and the still glass cover inclination is 15° for maximum annual yield of the solar still. Singh and Tiwari (2004) based on their detailed analysis concluded that the annual yield is at its maximum when the condensing glass cover inclination is equal to the latitude of the place and the optimum collector inclination for a flat plate collector is 28.58° for a condensing glass cover inclination of 18.58° for New Delhi climatic
conditions. Tripathi and Tiwari (2005) observed that, more yield is obtained during the off shine hours as compared to day time for higher water depths in solar still due to storage effect. Yadav and Prasad (1995) presented a performance analysis of a solar still integrated with a parallel flat plate solar collector (Figure 2.26). They indicated that parallel plate collector also increased basin water temperature higher than 50°C.

![Schematic diagram of single basin solar still coupled to parallel plate solar collector (Yadav and Prasad 1995)](image)

**Figure 2.26** Schematic diagram of single basin solar still coupled to parallel plate solar collector (Yadav and Prasad 1995)

Velmurugan and Srithar (2007) conducted experimental analysis of a mini solar pond assisted solar still (Figure 2.27) with sponge cube. The results show that, the average daily production of distilled water increased considerably while the sponged solar still is integrated with a mini solar pond. Pandey (1984) presented the effect of bubbling of ambient air and cooling of the glass cover (Figure 2.28). The author concluded that the efficiency of the still is increased by dry air bubbling and glass cooling. Singh et al (1996) presented an analytical expression for the water temperature of an active solar distillation unit with collectors and concentrator (Figure 2.29). The results show that the efficiency of the system with a concentrator is higher than that with a collector.
Figure 2.27 Mini solar pond assisted solar still (Velmurugan and Srithar 2007)

Figure 2.28 Schematic diagram of air bubbled solar still (Pandey 1984)

Figure 2.29 Cross sectional view concentrator assisted solar distillation system (Singh et al 1996)
Yeh and Chen (1985) concluded that considerable improvement in productivity may be obtained if the water vapor is carried away directly by the flowing air. A theoretical and experimental study was conducted to investigate the effect of adding a passive condenser on the performance of the single slope, basin type solar stills by Fath and Elsherbiny (1993). A theoretical model based on the Dunkle mass transfer (evaporation) rate was developed. The model assumes that the transfer of water vapour from the still to the condenser is due to one or more of the following mass transfer modes: (i) diffusion, (ii) purging, and (iii) natural circulation. The theoretical results indicate that the diffusion contribution is relatively small. The contribution through purging represents the fraction \( \frac{\text{condenser volume}}{\text{condenser volume} + \text{still volume}} \) of the still yield. About 75% of the still yield is contributed through natural circulation. An experimental study that simulates the purging mass transfer mode was investigated. The experimental results show good agreement with the theoretical predictions and an increase of 50% in the still efficiency. Characteristics of the different types of solar still including a comparison of their respective production rate of fresh water is given in Table 2.1.

2.5 STATUS OF SOLAR DESALINATION IN INDIA

The fresh water crisis is already evident in many parts of India, varying in scale and intensity at different times of the year. The fresh water crisis is not the result of natural factors, but has been caused by human actions. India's rapidly rising population and changing lifestyles also increases the need for fresh water. Intense competition among sectors like agriculture, industry and domestic users, is driving the ground water table deeper and deeper. Widespread pollution of surface and groundwater is reducing the quality of fresh water resources. Fresh water is increasingly taking centre stage on the economic and political agenda, as more and more disputes between and within states, districts, regions, and even at the community level arise.
<table>
<thead>
<tr>
<th>Type of solar still</th>
<th>Author(s)</th>
<th>Experimental results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wick type solar still</td>
<td>Sodha et al (1981)</td>
<td>Overall efficiency is 4% higher than the basin type still.</td>
</tr>
<tr>
<td>Multiple wick solar still</td>
<td>Tiwari and Selim (1984)</td>
<td>20% higher yield than the simple wick solar still.</td>
</tr>
<tr>
<td>Multiple solar still with condenser</td>
<td>Reddy et al (1983)</td>
<td>15 – 25% higher than non condenser type solar still</td>
</tr>
<tr>
<td>Multiple wick solar still</td>
<td>Dhiman and Tiwari (1990)</td>
<td>Yield increased by 10% when water is flowing over the glass cover in a very thin layer.</td>
</tr>
<tr>
<td>Solar still with placing the sponge cubes over the water surface</td>
<td>Abu-Hijleh and Rababa’h (2003)</td>
<td>The sponge cubes increased the surface area over which evaporation of water occurs, and caused the increase in output by 18%.</td>
</tr>
<tr>
<td>Solar still with black rubber mat, black dye and black ink</td>
<td>Akash et al (1998)</td>
<td>Using different absorbing materials like black rubber mat, black dye and black ink to enhance the still output by 30–40%.</td>
</tr>
<tr>
<td>Solar still with black granite</td>
<td>Sakthivel and Shanmugasundaram (2008)</td>
<td>The still yield is increased by 17% -20% compared with conventional still</td>
</tr>
<tr>
<td>Solar still with black rubber</td>
<td>Nafey et al (2001)</td>
<td>Black rubber (10 mm thick) improves the productivity by 20%.</td>
</tr>
<tr>
<td>Tubular solar still</td>
<td>Tiwari and Ashokkumar (1988)</td>
<td>The daily yield of distillate in the tubular solar still is higher than that of the conventional solar still.</td>
</tr>
<tr>
<td>Spherical solar still</td>
<td>Dhiman (1988)</td>
<td>The efficiency of spherical solar still is 30% more than that of the conventional solar still.</td>
</tr>
<tr>
<td>Type of solar still</td>
<td>Author(s)</td>
<td>Experimental results</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------------------------------------</td>
<td>---------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Solar still integrated with greenhouse</td>
<td>Sodha et al (1980)</td>
<td>The daily heat flux in the room gets reduced by 40%.</td>
</tr>
<tr>
<td>Double effect multiwick solar still</td>
<td>Singh and Tiwari (1992)</td>
<td>(i) Double effect distillation is more efficient for the low flow velocity required in the wick solar still and (ii) Overall thermal efficiency decreases with an increase of mass flow rate.</td>
</tr>
<tr>
<td>Inverted absorber solar still</td>
<td>Suneja et al (1997) and Suneja and Tiwari (1999)</td>
<td>The overall daily yield in the case of the inverted triple effect absorber solar still is 30% higher than the conventional triple effect solar still.</td>
</tr>
<tr>
<td>Cascade still</td>
<td>Headley (1973)</td>
<td>The thermal efficiency obtained was 60% - 75%.</td>
</tr>
</tbody>
</table>
| Effect of Water Capacity            | Malik et al (1982), Lawrence et al (1990), Yadav and Prasad (1995), Garg and Mann (1976) | (i) There is a variation of 30% in daily yield for variation in depth from 12.7 mm to 305 mm. and a lower glass cover angle gives higher output.  
(ii) For high altitude stations the long axis of the conventional double sloped still should face an east-west direction in order to receive more solar radiation. |
Table 2.1 (continued)

<table>
<thead>
<tr>
<th>Type of solar still</th>
<th>Author(s)</th>
<th>Experimental results</th>
</tr>
</thead>
</table>
| Effect of Inclusion of Dyes            | Akash et al (1998)            | (i) An absorbing black rubber mat increased the daily water productivity by 38%.  
(ii) Using black ink increased it by 45%.  
(iii) Black dye was the best absorbing material used in terms of water productivity. |
| Double condensing chamber solar still  | Tiwari et al (1997)           | The performance of double condenser chamber solar still gives a higher daily output of about 35% - 77% over the conventional solar still.               |
| Solar still with sun tracking system   | Abdallah and Badran (2008)    | The use of sun tracking increased the productivity for around 22%, due to the increase of overall efficiency by 2%.                                  |
| Solar still coupled with flat plate collector | Rai and Tiwari (1983)       | The average daily production of distilled water is 24% higher than the simple single basin solar still.                                               |
| Mini solar pond assisted solar still   | Velmurugan and Srithar (2007) | The average daily production of distilled water increased considerably while the sponged solar still is integrated with a mini solar pond.           |
Nearly one million children in India die of diarrhea related diseases each year directly because of drinking unsafe water and living in unhygienic conditions. Some 45 million people are affected by water quality problems caused by pollution, by excess fluoride, arsenic, iron or by the ingress of salt water. Millions do not have adequate quantities of safe water, particularly during the summer months. In rural areas, women and girls still have to walk long distances and spend up to four hours every day to provide the household with water (Kumar 2003).

Scarcity of fresh water problems are faced in many arid zones of Gujarat and Rajasthan, and luckily these places are getting more amount of solar energy. Apart from Gujarat and Rajasthan there are places in western India, which face water shortage and have huge underground saline water sources. Certain regions in Harayana state and Maharastra states also have underground saline water in spite of high rain fall (Gomkale and Datta 1973).

Desalination of brackish water and sea water to provide the needed drinking water fulfills a basic social need and it does this without any serious impact on the environment. The conventional desalination technologies like multi stage flash, multiple effect, vapor compression, iron exchange, reverse osmosis, electro dialysis are expensive for the production of small amount of fresh water, also use of conventional energy sources has a negative impact on the environment. Solar distillation provides partial support to human need of fresh water through free energy, simple technology without polluting the environment. Solar stills have a good chance of success in India for lower capacities which are more than 20 km away from the source of fresh water and where the TDS of saline water is over 10,000 ppm or where seawater is to be desalted (Gomkale 1988).
India, being a tropical country, is blessed with plenty of sunshine. The average daily solar radiation varies between 4 to 7 kWh per square meter for different parts of the country. There are on an average 250 to 300 clear sunny days a year. Thus, it receives about 5,000 trillion kWh of solar energy in a year. The annual global radiation varies from 1600 to 2200 kW / m² (Khanna et al 2008). The highest annual global radiation is received in Rajasthan and northern Gujarat. In spite of the limitations of being a dilute source and intermittent in nature, solar energy has the potential for meeting and supplementing various energy requirements. Solar energy systems being modular in nature could be installed in any capacity as per the requirement.

2.5.1 First Largest Solar Distillation Plant in India

The first largest solar distillation plant was installed by Central Salt and Marine Chemical Research Institute (CSMCR), Bhavnagar to supply drinking water in Awania village and Chhachi lighthouse in 1978. Awania is a non electrified village about 12 km from Bhavnagar with a population around 1400. Figure 2.30 shows the Awania plant layout. It consists of 90 stills each having evaporating surface of 20.74 m² equally distributed in 15 blocks having external dimensions of 12.66 m x 12.11 m with capacity of 5000 liters/ day.

Figure 2.30 Lay-out of solar distillation plant at village Awania (Natu et al 1979)
Natu et al (1979) gave their operation experiences at Awania village distillation plant. The villagers took some time to understand the difference between the quality of water produced by solar distillation plant and water from the well after which they started using plant water regularly. The authors indicated that, smaller plants serving smaller communities will be the right application of this technology in India. Some of the majorities of high capacity solar still plants in India were installed by the Central Salt and Marine Chemical Research Institute (CSMCRI) given in Table 2.2 (Gomkale 1988).
Table 2.2  Large size solar still installations put up by central salt and marine chemicals research institute, Bhavnagar (India) (Gomkale 1988)

<table>
<thead>
<tr>
<th>No</th>
<th>Location</th>
<th>Capacity (l/d)</th>
<th>Evaporating area (m$^2$)</th>
<th>Year of installation</th>
<th>Present status and other remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CSMCRI Salt works, Bhavnagar</td>
<td>1000</td>
<td>350</td>
<td>1965</td>
<td>Pilot plant supplied drinking water to labourers in salt works Damaged during heavy rains in 1968</td>
</tr>
<tr>
<td>2</td>
<td>Navinar Lighthouse near Mundra, Gulf of Kutch</td>
<td>130</td>
<td>49.9</td>
<td>1968</td>
<td>Needs repairs but still working Supplies drinking water to staff members</td>
</tr>
<tr>
<td>3</td>
<td>Awania village, near Bhavnagar</td>
<td>5000</td>
<td>1866.6</td>
<td>1977/78</td>
<td>Supplies drinking water to village Extensively damaged by cyclone in November 1982</td>
</tr>
<tr>
<td>4</td>
<td>Chhachl Lighthouse near Mandvi, Gulf of Kutch</td>
<td>250</td>
<td>108.0</td>
<td>1978/79</td>
<td>Needs major repairs Not properly maintained Damaged by stray dogs, etc</td>
</tr>
<tr>
<td>5</td>
<td>Narayana Sarovar, District Kutch, GuJarat</td>
<td>3000</td>
<td>1244.4</td>
<td>1983</td>
<td>Work started in 1977 but due to lack of saline water discontinued. Raw water supply discontinued in 1985 and nobody took over the plant. Project abandoned in 1987</td>
</tr>
<tr>
<td>6</td>
<td>Bhalen, District Churu, Rajasthan</td>
<td>8000</td>
<td>3110.0</td>
<td>1979</td>
<td>Constructed by PHED, Rajasthan. Faces problems in supply of saline water for operating entire plant. Windmill for pumping saline water</td>
</tr>
<tr>
<td>7</td>
<td>Bitra Island, Union territory of Lakshdweep</td>
<td>2000</td>
<td>750.0</td>
<td>1983</td>
<td>Constructed by PWD Provides drinking water to islanders</td>
</tr>
</tbody>
</table>
A first double slope solar distillation unit was installed (Figure 2.31) with capacity of 85 liters/day at IIT, Delhi, in January 1981, to meet the requirements of the Chemistry Department. The unit consisted of 28 multi wick solar stills each of 1 m$^2$ effective area with four stills in a row. Each row of stills had independent feeding water pipes connected to a small storage tank. Due to high wind speed, power shortage, algae formation etc, the plant was dismantled in June 1982 and reinstalled in October 1982 with some improvements (Tiwari 1984).

2.6 CONCLUSIONS

Following are the important conclusions drawn from the above literature review:-

- The simple conventional solar still is more economical than active solar distillation system to provide drinking for the domestic applications.
- A single sloped solar still receives more radiation than a double sloped solar still at low and high altitude stations.
- Lower condensing cover angle yield is more compared to higher condensing cover angle.
- Solar still productivity mainly depends on temperature difference between water and glass.
- The effect of water flow over the glass cover has a significant effect on the heat capacity of water mass in the basin.
- The still consisted of a vertical conical shaped blackened cotton wick (representing absorbing/evaporating surface) with good capillarity is increasing the yield.
• Energy storage medium increases the solar still productivity and efficiency.

• An addition of black dye increases the daily productivity and the efficiency of the system by about 10%.

• Solar stills in combination with greenhouses could be designed to provide technically feasible systems suitable for arid areas.

• In active solar distillation system the optimum flat-plate collector inclination is 20° and the still glass-cover inclination is 15° for a solar still which provides maximum annual yield.

• The active solar still is more suitable for commercial applications like distilled water for selling purposes, extraction of essence from different seeds and green leaves, use in batteries, chemical laboratories etc.

• Solar stills have a good chance of success in India for lower capacities which are more than 20 km away from the source of fresh water and where the TDS of saline water is over 10,000 ppm.

• To decrease fresh water costs, efforts should be undertaken in the following research topics: thermal storage studies, insulation studies, thermo-optical studies for the condensing covers, geometry and design studies.

From the above discussions various parameters involving the conventional solar still productivity are identified. The main objectives and methodology employed in the experimental studies and the evaluation of convection and evaporative heat transfer coefficients in the present studies are described in the next Chapter – 3.