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Solar desalination

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Abstract: This paper outlines the state of the art in solar desalination, especially atmospheric and vacuum distillation with or without condensation heat recovery, and focuses on the ongoing progress and the targets achievable.

Keywords: atmospheric distillation; vacuum distillation; condensation heat recovery; solar desalination.

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Biographical notes: Marco Rognoni graduated in Chemical Engineering in 1969 from the Politecnico of Milano (Italy) and completed his PhD in 1974. After some experience in various countries in North Africa and the Middle East, he has devoted himself to desalination processes since the early 1980s. A former technical manager and MD of SOWIT, he is now Chairman of Saline Water Specialists (SWS) based in Italy and SWS & GB, based in India, both active in the design and realisation of thermal desalination plants (MSF, MED, MVC). He designed and supervised over 30 plants now in successful operation all over the world. He is a member of EDS and the Indian Desalination Association, and is the author of several scientific publications and of patents applicable to desalination plants, including the SED system.

1 Introduction

Desalination is a process that requires large amounts of energy, regardless of the applied desalination technology. The difference in the entropy content between fresh water and saline water has to be overcome by spending energy according to the principles of thermodynamics.

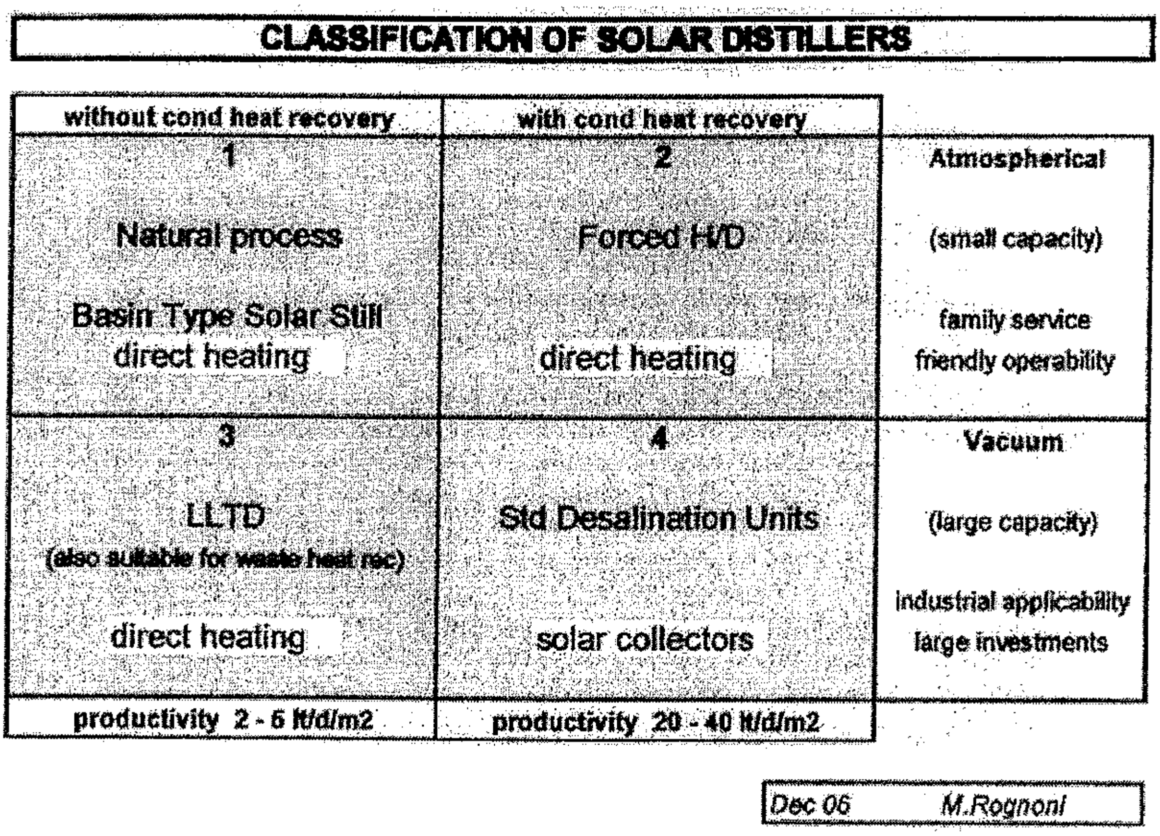
The rapid increase in the cost of energy is now drawing attention towards the recovery of waste energy and the use of renewable sources of energy. Solar energy is the most promising renewable energy for application to desalination, even if the major problem of energy collection is the limit on the size of the desalination plants.

This paper consists of the following sections:

1 Atmospheric distillation without condensation heat recovery
2 Atmospheric distillation with condensation heat recovery
3 Vacuum distillation with condensation heat recovery
4 Vacuum distillation without condensation heat recovery
5 Comments and conclusions.

The intensity of solar irradiation varies between 07 and 1.5 kW/m^2, according to the day time, weather and latitude. This is a very small amount of energy compared to the requirements of desalination. Therefore, large collecting areas are necessary, whatever the collecting means (direct or indirect) and whatever the eventual system of energy concentration.

Figure 1 Classification of solar distillers



With direct heating (no energy concentration), the productivity of each square metre of surface exposed to the solar rays is 2–5 litres per day.

The designers of solar desalination plants usually consider the maximum productivity to be 1.5 m^3/m^2/y.

These values of productivity are applicable without the recovery of the condensation heat therefore in conditions of Gained Output Ratio (GOR) = 1. Higher productivity can be achieved with plants equipped with systems for the recovery of the condensation heat, thus ensuring higher values of GOR.

The recovery of condensation heat is possible or convenient only when the difference in temperature is large between the warm evaporating water and the cold condensing water.

The high efficiency of the desalination plant reduces the amount of energy and the surface of collecting area, but needs the concentration of energy, thus requiring the proper equipping of the collecting area.

The production of 1000 t/d of fresh water corresponds to a small industrial desalination unit. This production, if energised by solar energy, would require 25 hectares of collecting surface (in the case of no-condensation heat recovery), which sounds infeasible in most cases.

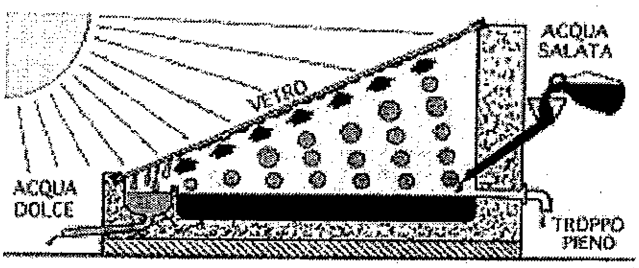
If the solar heat is concentrated adequately to allow for higher GOR, the surface may be well reduced to 2.3–3 hectares, but this surface is to be equipped with proper concentration systems (typically mirrors). Even this solution is infeasible in most cases.

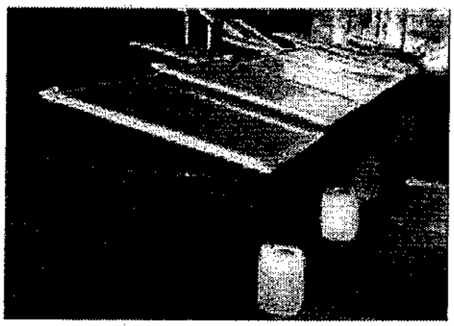
The search for the best compromise between the cost of collecting solar energy and the cost and efficiency of the desalination plants has led to different families of plants. A classification of the families of plants can be attempted as (a) dividing the plants according to the condensation heat recovery and (b) the type of operation (vacuum or atmospheric).

2 Atmospheric distillation without condensation heat recovery

This process is the one that takes place in nature, when the evaporation of seawater from the surface of the ocean generates humidity. This humidity condenses in the higher and cold layers of the atmosphere and generates clouds and rain. This process can be easily reproduced in artificial basins exposed to solar irradiation (Figure 2), with a normal productivity of approximately 2.5 to 3 l/d per square metre of basin area.

Figure 2 Solar seawater desalination scheme (left); solar desalination plants (right)





The ceiling of the basin is made of glass that allows the sun's rays to pass through and warm up the seawater lying on the floor (better painted black). The air inside the basin becomes saturated with humidity at the warm temperature. The vapour condenses on the covering glass, which is colder because of contact with the external atmosphere. The droplets of condensate flow along the glass, properly installed at an angle, and are collected as fresh water. Many plants of this type have been designed, tested, fabricated and installed in remote areas.

In Maharashtra, there is an industrial shop that fabricates standard units of 1 m^2 available at about 5000 INR each. The use is of course limited to specific cases as a sort of survival kit.[1]

The operation can be made very easy and friendly. The seawater can be brought manually to the plant at the rate of approximately 10 l/d per square metre and poured into the basin. At the end of the day, approximately 3 litres of fresh water are available per square metre of basin. No rotary equipment, instruments and controlling devices are necessary for the entirely natural operation.

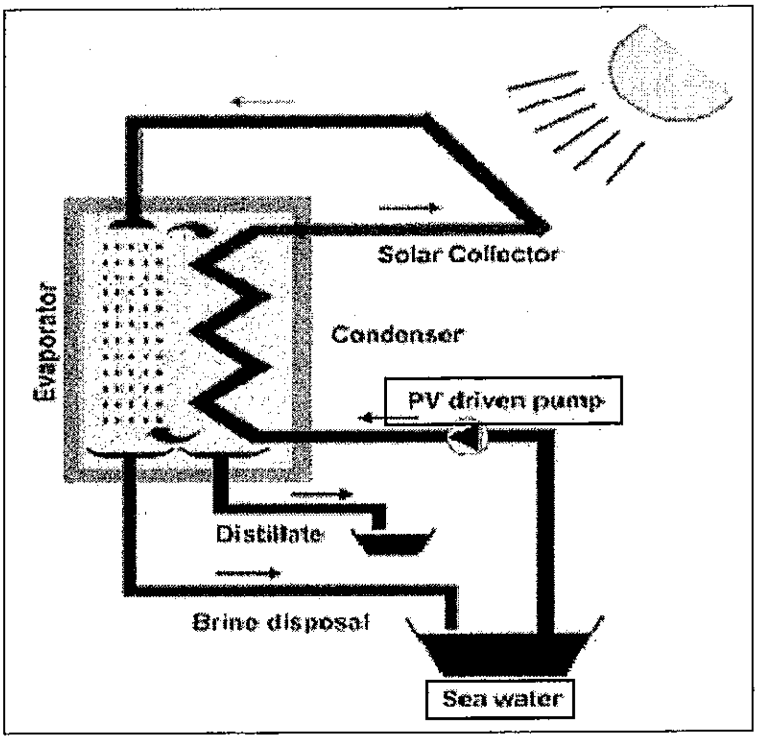
Larger units can be designed, but the production rate is in any case within the limit for survival purposes, without feasible possibilities to match the full, real need of the people.

3 Atmospheric distillation with condensation heat recovery

The natural process described above can be enhanced with the recovery of the condensation heat, thus ensuring much higher production per square metre of solar collecting surface.

For this purpose, the condensation is made on a surface contacted by the seawater fed to the evaporation basin, typically through a serpentine tube (Figure 3). In most cases the humid air is forced from the evaporation room to the condensation room by a fan that helps the natural flow of air and enhances the productivity. The largest plant of this type was installed in Mexico in the 1960s with the total capacity of 20 m^3/day, serviced by 800 m^2 of irradiated basin.

Figure 3 Atmospheric distillation with condensation heat recovery



Plants of this type are adequate to produce five or more times the production of the natural evaporation basin, up to 30 l/m^2/d.

A plant built up in a container-shaped skid may therefore produce approximately 350 m^3/d on the average, with a design peak of about 80 lt/h.

In this case a seawater pump is used for the continuous feed to the plant, and some electricity consumption is to be considered. The typical consumption per cubic metre of fresh water is approximately 2 kWh for the seawater pump and 1.5 kWh for the fan (if installed), thus totalling a very small impact of the auxiliary energy.

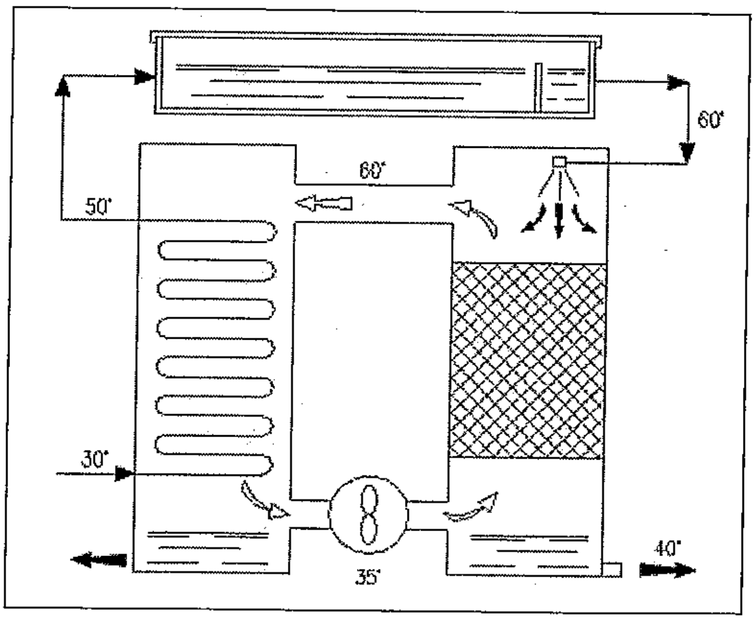
This brings the total consumption to approximately 0.3 kW during the operating hours (approximately 7 h when the light is maximum) for the plant considered below (350 l/d).

The typical design data for the 80 l/h design production rate are the following:

- seawater flow 1500 kg/h at 30°C
- seawater preheating temp 50°C
- seawater solar temp increase from 10°C to 60°C, thus absorbing 1.2 kW/m^2 per 15 m^2 of area exposed to solar irradiation
- air recirculated by fan 450 Nm^3/h warmed to 60°C and cooled to 35°C
- humidity carried at 60°C saturated = 120kg/h
- humidity carried at 30°C saturated = 40 kg/h.

This arrangement is equivalent to GOR = 3, being the heat recovered twice the solar input. However, higher GOR rates can be achieved by increasing the surface of the heat recovery tubes.

Figure 4 Combined solar power and desalination system



4 Vacuum distillation with condensation heat recovery

This is the usual process to produce distillate in industrial evaporators arranged as MSF, MED or TVC. The innovation is present in the system of concentrating the solar energy so as to reach high temperatures and produce steam at high pressure. Very large irradiated areas are necessary for this purpose, equipped with advanced systems of concentration of the energy in the water pipes and installed with orientable parabolic mirrors.

Many successful experiments are now in progress in Germany, and steam up to 100 bar has been produced. Based on this growing technology, power can be generated and any traditional desalination plant can be combined with the power generation.

The cogeneration arrangement coming from the expansion of the steam in a turbine and the feeding of the backpressure steam to a desalination plant, is also of great interest.

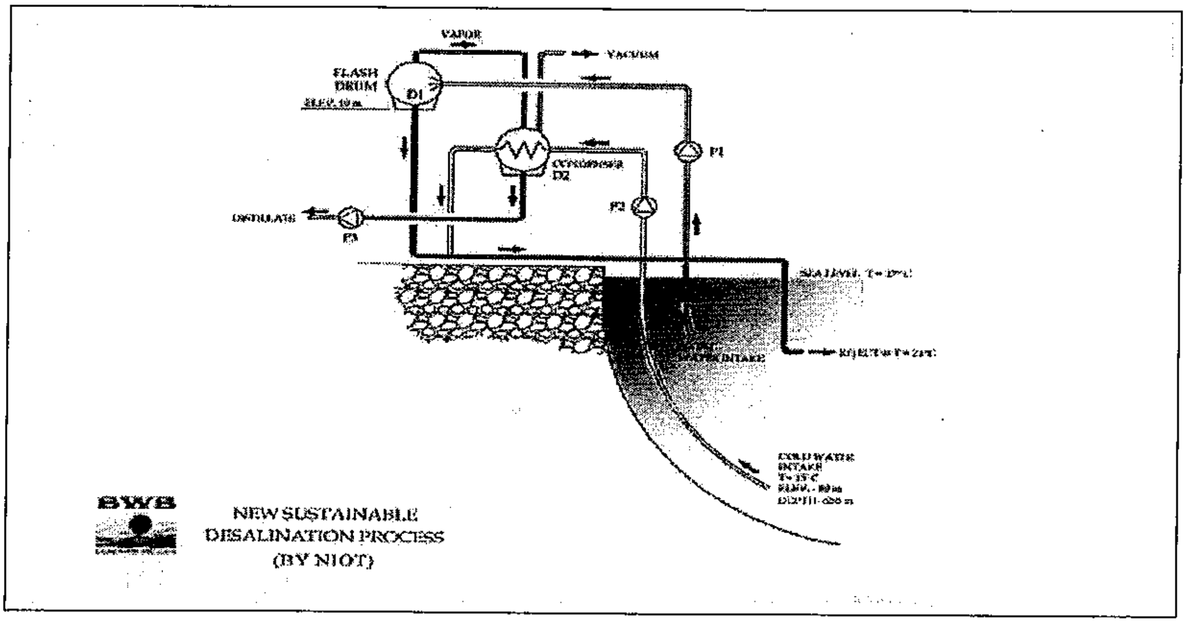
However, no innovation in the desalination design is necessary to match any requirement coming from the origin of the primary energy and therefore this topic is not detailed any further in this paper.

5 Vacuum distillation without condensation heat recovery

This system seems to be the most promising because of the good compromise between the simplicity of the installation, without the recovery of the condensation heat and the enhanced production capacity owing to the vacuum operation. In fact, very low working temperatures can be set while maintaining boiling conditions and no concentration of the irradiated energy is therefore necessary.

The production of large quantities of fresh water requires, however, large irradiated surfaces. The technology now being implemented in India by the National Institute of Ocean Technology (NIOT) exploits the largest surface available, that is, the surface of the ocean (Figure 5). The name given by NIOT to this technology is LLTD (Low-Level Temperature Desalination).

Figure 5 Low-level temperature desalination process developed by NIOT



In India, very favourable conditions are available in nature in this respect. The surface of the ocean is, in fact, at a fairly stable warm temperature across the seasons, between 28°C and 30°C, whilst rather cold temperatures are available in the deep sea, average of 13°C or 14°C.

In this condition, the flash of the warm surface water can be arranged down to an intermediate temperature, and the vapour can be condensed by the cold water pumped from the deep sea.

This technology requires both the good knowledge of the ocean status, including temperature profile, depth, currents and frequency of storms, and the good knowledge of the desalination process, including the process of large flow and the venting of the incondensable gases coming from the large processed flows. The fresh water recovery ratio is, in fact, about 1% (or less) of the processed sea water. This is not a problem of availability because the ocean is a vast source of water, but it is a serious problem of handling and venting, with the target of limiting the consumption of energy for the auxiliary equipment. The optimisation is well in progress with wide possibilities of further optimisation, to encourage the optimistic forecast of diffusion of this technology.

After running a pilot plant in its premises and in Vizag Steel Plant, the NIOT put up a real production plant rated 100 t/d that was installed in the island of Kavaratti very successfully over a year ago. Based on that experience, the NIOT equipped a barge with two units rated 500 t/d and is now completing a plant for the Andaman Islands rated 50 t/d.

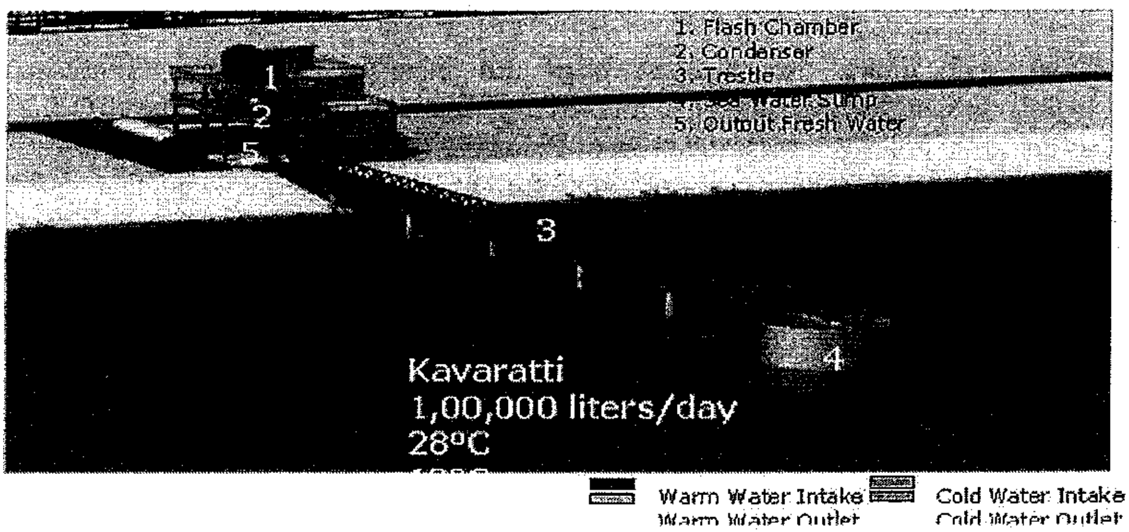
A large project of seven plants to be installed in the Lakshadweep islands is now being implemented.

The progress achieved in the optimisation of the consumption of energy for the auxiliary equipment is quite impressive. From the 11 kW/m^3 of the plant of Kavaratti, the new project at Lakshadweep will have a consumption of less than 8 kW/m^3, and new progress is foreseen up to the final target of nearly 4 kW/m^3.

The plant is very simple mechanically and can be monitored and maintained by the same unskilled people of the islands, who was proven to be inadequate to run the previous reverse osmosis plant (unsuccessfully installed in the Kavaratti island, before being replaced by the NIOT).

One of the most interesting features of this technology is the applicability of the design criteria of the desalination plant to other situations of industrial installation. A very similar plant was designed by the engineers of SWS in Italy, fabricated and successfully installed in the Power Plant of ENEL at Piombino (Italy) in 1992. This plant is rated up to 25 t/h (approximately 600 t/d), but the instantaneous production naturally fluctuates with the load of the power plant.

Figure 6 The NIOT plant installed at Kavaratti



In this application the flows of warm and cold sea water are not provided by the exploitation of the thermal content of the ocean, but are given by the following sources:

- The existing seawater intake, designed for the cooling of the turbine condensers (four steam cycles of 320 MW (total 1260 MW) each fuelled by oil)
- The channel of discharge of the sea water from the turbine condenses, warmed up to 8°C by the condensation of the steam.

This plant is therefore working in a more difficult situation than the ocean application of the NIOT, because the flash range available is approximately half of that available in the Indian Ocean.

Nevertheless, the plant was proven to work satisfactorily in all the ambient conditions, even in winter when the measured temperature of the sea was 11°C and the warm temperature not exceeding 19°C (typical conditions in the Mediterranean Sea).

In this application, the recovery ratio of seawater is approximately 0.5%; that is, however, not a problem, as there are massive flows available according to the efficiency of the steam cycle of the power plant. The main problem to be solved was the vent of the incondensable gases released at very low pressure by the flow of water 200 times larger than the production. In the case of Piombino, the problem was solved conveniently with steam ejectors fed by some waste steam available in the power plant.

Since then, however, some process improvements were studied and are now available, including the progressive deaeration at different levels of vacuum, thus reducing the total duty of the system.

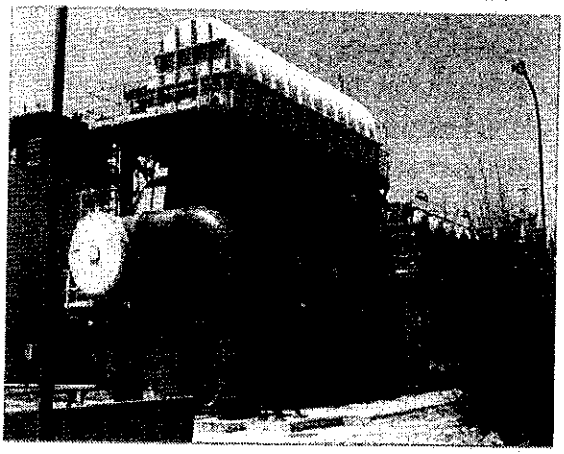
Besides the remarkable saving of primary energy, this plant has been granting a number of valuable advantages assessed by the operators of ENEL during 14 years of operation:

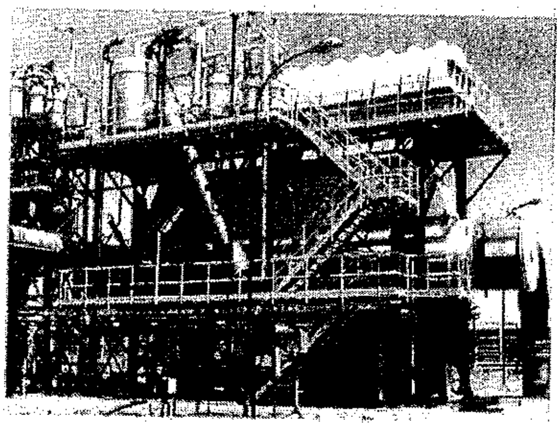
- The regularity and reliability of the plant is extraordinary. In 14 years, the plant has been working continuously without stop for maintenance and cleaning.
- The quality of the distillate is very high. The conductivity is below 1 μS/cm and we understand that most of it is due to the dissolved CO_2, such that TDS is deemed below 0.2 ppm. This requires very little or no polishing for feeding the distillate to the boilers as make-up, the CO_2 being vented by the deaerator.
- No chemical addition is necessary, because the additives already added for the condensation service are also adequate for the desalination service, as present in the warm water flow pumped into the flash chamber.

In future applications, this type of plant can incorporate all the technological improvements achieved through the combined experiences of SWS and of the NIOT.

Before these improvements, the plant of Piombino (single low temperature flash; see Figure 7) had a total energy consumption for the auxiliary equipment that can be compared with a traditional MSF unit of GOR = 22. With the new improvements, the same comparison will ensure an equivalent GOR of over 35; this cannot be achieved by any other technology now in use.

Figure 7 The Piombino power plant





PIOMBINO POWER PLANT - 1x600 CSUD UNIT (RIGHT) LATERAL VIEW

5 Comments and conclusions

Solar energy is available at such low intensity that its recovery may be very expensive in many circumstances. The convenience in recovering the solar energy depends on the comparison with the cost of other sources of energy suitable for the same service. As the cost of fossil energy is now predicted to continue to increase, the circumstances of convenience of solar energy are predicted to increase as well, and the exercise of optimising the installation is now a must in several fields of application.

Desalination is a process that requires large amounts of energy and therefore the advantages and disadvantages of the recovery of the solar energy are much inflated.

Compared with other uses, however, desalination is among those that require the lowest temperatures, and accordingly the solar energy can be more easily recovered from natural basins of accumulation, or collected without investing in concentrators. When no concentration of solar energy is necessary, the desalination plants can be optimised for the specific condition of operation, and some remarkable improvements in the usual design are achievable, mainly in the case of vacuum operation.

Note

1 Please refer to www.mahaurja.com/desalination_system.html.