MULTIPLE EFFECT DISTILLATION OF SEAWATER USING SOLAR ENERGY – THE CASE OF ABU DHABI SOLAR DESALINATION PLANT

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Summary

This chapter describes the solar desalination test plant in Abu Dhabi, UAE and gives a summary of its first year performance and economics. The plant has been operating successfully for 18 years supplying fresh water to the City of Abu Dhabi. The plant was commissioned in September 1984 and was running until the year 2002 when it was dismantled after fulfilling its objectives.

The aim of the plant is to investigate the technical and economic feasibility of using solar desalination of seawater in providing fresh water to remote communities in the Middle East and to obtain long-term performance and reliability data on the operation of the plant.

The plant has proved its technical feasibility and proved to be reliable in operation with few minor maintenance problems that required slight plant modification. Maintenance routines were established to maintain high plant performance.

The economic feasibility of the plant was established by comparing the cost of water from a solar MED plant with a conventional MED plant using fossil fuel for plant capacity ranging from 100 m^3/day to 1000 m^3/day. It was found that the cost of water from solar MED plants is competitive with that from a conventional MED plant if the cost fuel continues to rise.

1. Introduction

Many remote areas of the world such as coastal desert areas in the Middle East or some Mediterranean and Caribbean islands are suffering from acute shortage of drinking water particularly during the summer season. Drinking water for these locations are normally hauled in by tankers or barges or produced by small desalination units using the available saline water.

The transportation of water by tankers or barges involves a lot of expense and is fraught with logistical problems which can make fresh water not only very expensive when available but also its supply being very susceptible to frequent interruptions.

The use of small conventional desalination units using a fossil fuel such as diesel oil as the energy supply can suffer from the same procurement problems that are encountered with transporting fresh water, namely transportation expenses and supply reliability.

Figure 1 Picture of Abu Dhabi solar desalination plant

Some of the remote areas are blessed with abundant solar radiation which can be used as an energy source for small desalination units to provide a reliable drinking water supply for the inhabitants of the remote areas. Recently, considerable attention has been given to the use of solar energy as an energy source for desalination because of the high cost of fossil fuel in remote areas, difficulties in obtaining it, interest in reducing air pollution and the lack of electrical power source in remote areas. Desalination of seawater and brackish water is one of the ways for meeting future fresh water demand. Conventional desalination technology is fairly well established, and some of the processes may be considered quite mature although there is still considerable scope for improvement and innovation.

Conventional desalination processes are energy intensive, and one of the major cost items in operating expenses of any conventional desalination plant is the energy cost. Thus, one of the major concerns about using desalination as a means of supplying fresh water to remote communities is the cost of energy. Apart from energy cost implications, there are environmental concerns with regard to the effects of using conventional energy sources. In recent years it has become clear that environmental pollution caused by the release of green house gases resulting from burning fossil fuels is responsible for ozone depletion and atmospheric warming. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on growing reliance on renewable sources of energy.

A solar-assisted desalination plant was designed, constructed and put into operation on September 1984 as part of a cooperative research program between Japan and the United Arab Emirates (UAE) to test the technical and economic feasibility of using solar energy for desalination of seawater [El-Nashar a,b,c (2000), El-Nashar (2001)]. The plant (see Figure 1) has been in operation in a Umm Al Nar near Abu Dhabi City until the year 2002 when it was dismantled. This report describes the main features of the first year of operation and compares its economics with conventional systems using the same desalination technology.

2. History of Abu Dhabi Solar Desalination Plant

In July 1979, when Mr. Ezaki, the then Japanese Minister of International Trade and Industry, visited the United Arab Emirates (UAE) and discussed the utilization of solar energy utilization in the UAE with Dr. Mana Saeed Al-Otaiba, the UAE Minister of Petroleum and Mineral Resources, they agreed on a joint project between the two countries to develop solar energy utilization for desalination of seawater.

Under this agreement, several discussions were held at various levels. On January 22, 1983, the Record of Discussion (ROD) was finally signed for the joint implementation of a Research and Development Cooperation on Solar Energy Desalination Project by the New Energy Development Organization (NEDO) in Japan, and the Water and Electricity Department in the Abu Dhabi Emirate of the UAE[ENAA & WED (1986)].

An outline of the ROD is as follows:

- Execusion period of the project is 3 years starting January 22, 1983
- Location of the project is Umm Al Nar in the suburbs of Abu Dhabi City
- Product water capacity of the test plant has a yearly average value of 80 m^3/day
- Research operation period of the test plant is one year
- Japanese project executor: Engineering Advancement Association of Japan (ENAA)

The design, procurement and fabrication of the test plant started in February 1983 and the test plant was completed in October 1984. For the following year, research operation on the test plant was jointly conducted by ENAA and WED and was concluded in October 1985.

Upon completion of the cooperative research project, the test plant was put in operation and was used as a research tool for a number of research projects carried out by WED. The plant was decommissioned in June 2002 after successfully operating for 18 years producing fresh water to Abu Dhabi City.

3. Description of Abu Dhabi Solar Desalination Plant

The solar desalination plant is designed for an expected yearly average fresh water production of 80 m^3/day. A simplified schematic of the plant is shown in Figure 2.A bank of evacuated tube solar collectors, whose orientation with respect to the sun has been optimized to collect the maximum amount of solar radiation, is used to heat the collector fluid to a maximum temperature of about 99°C. The effective collector area of this bank is 1862 m^2.

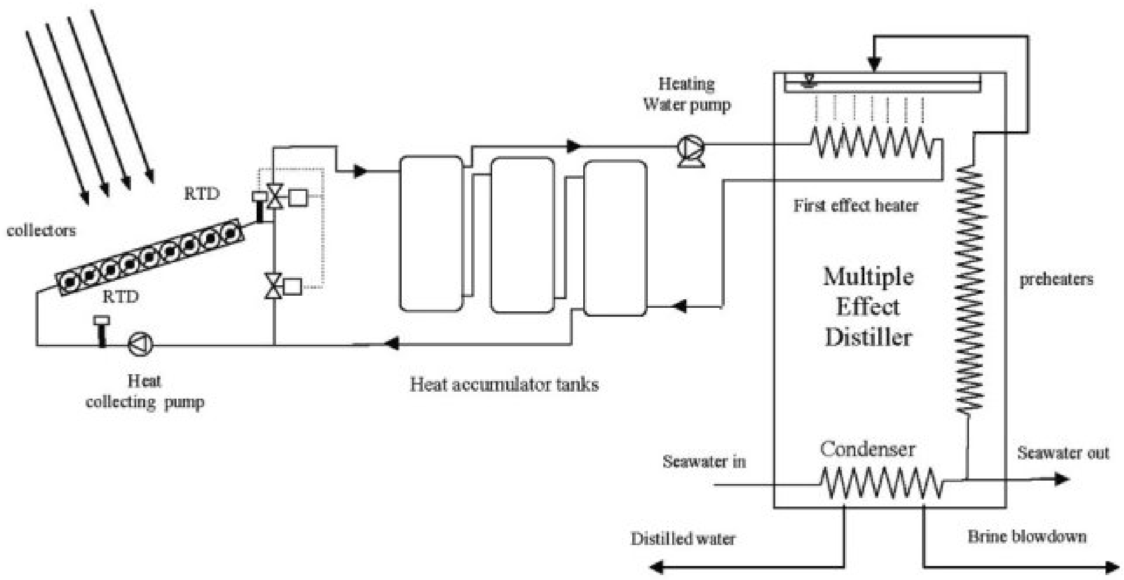

Figure 2 A simplified schematic of the solar desalination plant

The heat collecting water leaving the collector bank flows into the top of the heat accumulator which has a total capacity of 300 m^3. The heat accumulator is of the thermally stratified liquid type where, by virtue of density variation between the top and bottom layers, the higher temperature water is located in the upper region of the accumulator tank while the lower temperature water occupies the lower region. The lower temperature water is drawn from the tank bottom and pumped through the collectors by the heat collecting pump which has a capacity of $80m^3$/hr at 26m discharge head. The heat collecting water is drawn from the top of the accumulator tank by the heating water circulating pump and is forced to flow into the heating tubes of the first effect of the MED evaporator. This evaporator is designed for a maximum distillate production of $120m^3$. By transferring heat to the cooler brine flowing on the outside of the tubes, the heating water is cooled down and is then discharged into the accumulator.

The MED evaporator has 18 effects stacked one on top of the other with the highest temperature effect (No. 1) located at the top of the stack and the lowest temperature effect (No. 18) located at the bottom. The 18 effects are actually arranged in a double-stack configuration where effects 1, 3, 5,….17 are in one stack and effects 2, 4, 6…18 in the second. The double-stack arrangement is incorporated into one evaporator vessel as will be shown in detail later.

In addition to the 18 effects, the evaporator has a final condenser designed to condense the vapor generated in the bottom (last) stage (No. 18). Heat input supplied to the first effect by the heating water is repeatedly used by evaporating a portion of the brine flowing into each effect. The evaporator operates under vacuum that is effected by a positive displacement pump connected to the final condenser. The absolute pressure to be maintained in the final condenser is designed to be 50 mmHg. The pressure to be maintained in each effect varies from slightly below atmospheric in the first effect to about 50 mmHg in the 18^{th} effect.

Seawater is used to condense the vapor generated in the 18th effect. Part of the discharged warm seawater leaving the final condenser returns to the sea, while the other part constitutes the evaporator feedwater. The feedwater flow rate amounts to 17.3 m^3/hr; it flows through 17 preheaters before reaching the first effect, one preheater for each effect except the 18th effect. These preheaters are designed to raise the feedwater temperature incrementally by flowing from the bottom effect (No. 18) to the top effect (No.1).

3.1 Plant Description

3.1.1 The solar heat collector subsystem

The solar energy collecting system (SECS) has the function of collecting the solar energy when it is available during the day using the collector bank and storing this energy in the heat accumulator which supplies thermal energy to the evaporator with minimum fluctuations in the supply temperature. This is desirable since steady state operation of the evaporator near its optimum operating condition is highly recommendable.

The basic unit in the collector bank is the Sanyo evacuated tube solar collector which is shown in isometric in Figure 3. This is a flat plate-type collector that employs selective coating absorber plates enclosed in glass tubes maintained under high vacuum of 10^{-4} mm Hg. Ten glass tubes with their absorber plates are incorporated in each collector. Along the centerline of each glass tube is located a single copper tube which is attached to the middle of the absorber plate. The heat collecting water flows through this center pipe and absorbs the solar energy collected.

The ends of each glass tube are sealed to a special stainless steel end cap using a ceramic glass material having a coefficient of thermal expansion approximately the same as that of the glass tube. The difference in the thermal expansion between the copper tube and the glass tube is taken up by bellows installed between the end cap and the copper tube. Each collector consists of 10 individual tubes arranged in parallel. The heat collecting water moves inside the center tubes in a parallel/series arrangement whereby in five of the tubes the flow is in one direction and in the other five it is in the opposite direction.

Attached to one end of the center tubes is a header tube with an orifice located in the middle of the header tube. The other ends are connected to return bends which are used to connect pairs of center tubes in series. Several collectors (14 in number) are connected in series by coupling the different header tubes. Each collector has an absorber area of 1.75 m^2 and is coated with a black selective coating having an absorptivity, $\alpha \geq 0.91$ and an emittance, $\varepsilon \leq 0.12$. The specifications of a single collector as provided by the manufacturer are shown in Table 1.

Item	**Specification**
Selective coating	Absorptivity $\alpha \geq 0.91$
	Emissivity $\varepsilon \leq 0.12$
Absorber area	1.75 m^2

External dimensions	2860 mm × 985 mm × 115 mm
Net weight	64 kg
Flow rate	700 – 1,800 lit/hr
Max. operating pressure	6 bar

Table 1 Specifications of a single collector

The collector bank consists of 1064 collector units making up a total collector area of 1064 × 1.75 = 1862 m2. 28 collectors are combined to form a single array pair of collectors with its own support structure as shown in Figure 4. Each array pair consists of two parallel stacks of collector with each stack consisting of 14 collectors in series. The array pair is 14.5 meters long and 6.0 meters wide and is oriented in the north/south direction at a slope of 1/50. Water is supplied from the main pipe on the south side and passes through the 14 collectors connected in series and exit into the main pipe on the north side.

Figure 3 Isometric view of a collector

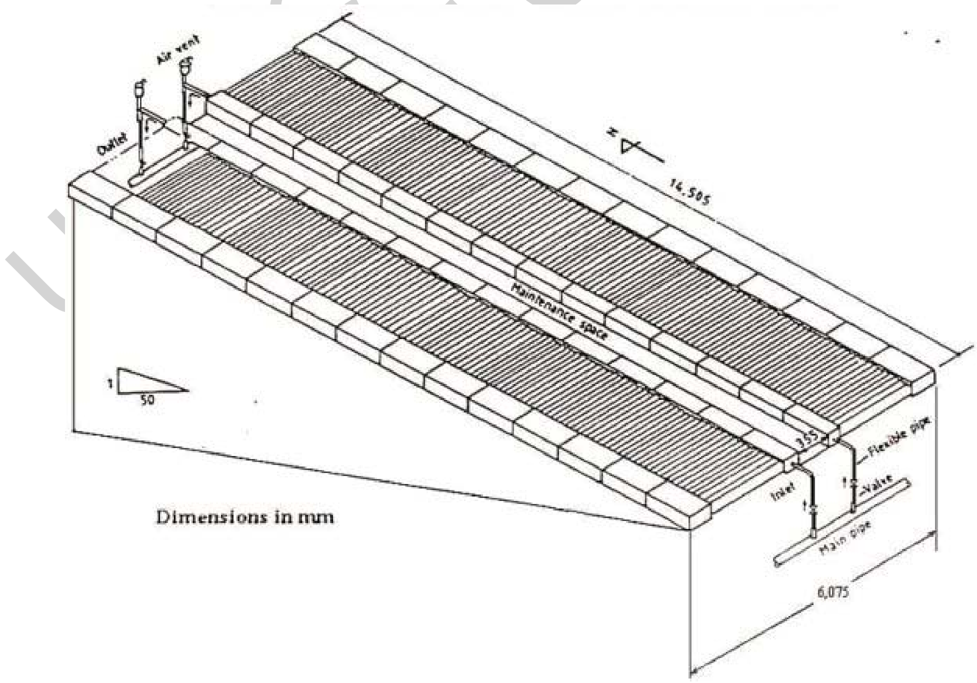

Figure 4 One array pair

76 array pairs are arranged in a U-shape to form the whole collector bank. All array pairs are connected in parallel and each is provided with two isolating valves- at inlet and exit-, a drain valve, and an air vent. The bank is divided into six blocks designated A, B, C, D, E and F. Blocks A and F consists of 12 array pairs while the other blocks each consists of 13 array pairs. Figure 5 is a block diagram of the collector field.

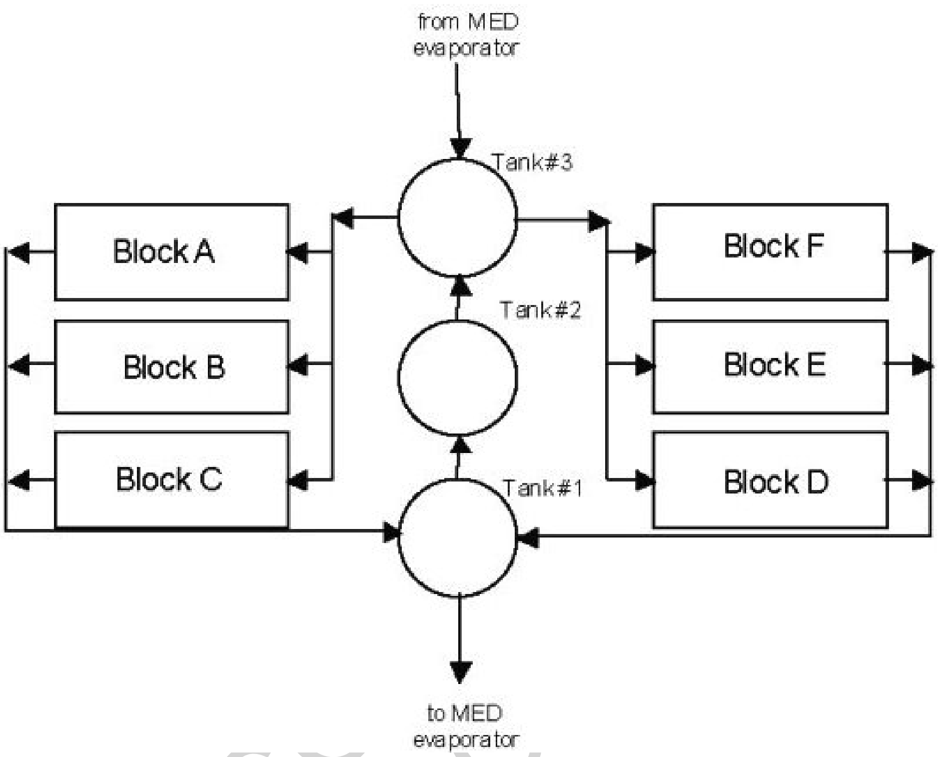

Figure 5 Collector bank consisting of six blocks A, B, C, D, E and F

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Biographical Sketch

Ali M. El-Nashar received the B.Sc. (Mech. Eng.) from Alexandria University (Egypt) in 1961 and Ph.D. (Nuclear Engineering) from London University (UK) in 1968. He has been a faculty member at several universities in Egypt, UK and USA and was appointed professor of mechanical engineering at Florida Institute of Technology (USA) and Mansoura University (Egypt). He was a research fellow at Clemson University (USA) during the period 1971 to 1976. He has worked as consultant for different industrial and UN organizations among which Dow Chemical Co. (USA), Ch2M-Hill Co. (USA), Science Application Co. (USA), UNEP, Technology International Co. (USA). He is member of the ASME, ISES and IDA and editor of the International Desalination and Energy journals. He has worked at the Research Center of the Abu Dhabi Water and Electricity Authority (UAE) as manager of the desalination and cogeneration section which pioneered development work on solar desalination for ADWEA for 20 years.