MECHANICAL AND THERMODYNAMIC PERFORMANCE ANALYSIS OF A MULTISTAGE DESALINATION SYSTEM

Robert Innis McElroy

Department of Mechanical and Industrial Engineering

APPROVED:

Dr. P. Golding, Chair

Dr. A. H. P. Swift

Dr. A. J. Tarquin P.E.

Associate Vice President for
Research and Graduate Studies

MECHANICAL AND THERMODYNAMIC PERFORMANCE ANALYSIS OF A MULTISTAGE DESALINATION SYSTEM

by

Robert Innis McElroy, BSME

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTERS OF SCIENCE

THE UNIVERSITY OF TEXAS AT EL PASO

May, 1993

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. Peter Golding, Associate Professor of the Mechanical & Industrial Engineering Department, for his help and support in the preparation of this thesis. Also, I wish to thank Dr. Andrew Swift, Associate Professor of the Mechanical & Industrial Engineering Department and Dr. Tony Tarquin P.E., Professor of the Civil Engineering Department for their support, help and for serving as committee members. I also wish to thank my friends and co-workers at the El Paso Solar Pond, and both the Mechanical Engineering Department and Resources Conservation Company for financial support without which, this research would not have been possible. Finally, I give special thanks to Ferris Standiford, the inventor of the Spinflash multieffect distillation system. His vast contributions to society through the advancement of desalination technologies are evident in his many excellent publications and inventions so unselfishly researched and produced for the benefit of all mankind. Mr. Standifords' life long work has created the roadmap for all engineers engaged in the quest to providing pure water, the mainstay of all life, for the worlds populations.

ABSTRACT

A "Spinflash" multistage flash evaporator, installed in the arid desert southwest of the United States, and coupled to a salinity-gradient solar pond, has been tested to establish the feasibility of desalination of brackish groundwaters for potable water supply. A 2000 gallon artificial feed supply was used to simulate actual groundwater. Both mechanical and thermodynamic operation of the system were investigated. During 1988, 263 hours of actual run-time was accrued. Data logged during this period has been analyzed to determine production rates, product water purity and economics of operation, as functions of several operational variables. Mechanical problems associated with the system are discussed and enhancements are suggested. Finally, an economic analysis is presented to compare produced water costs to the cost of municipal potable water.

TABLE OF CONTENTS

LIST OF TABLES

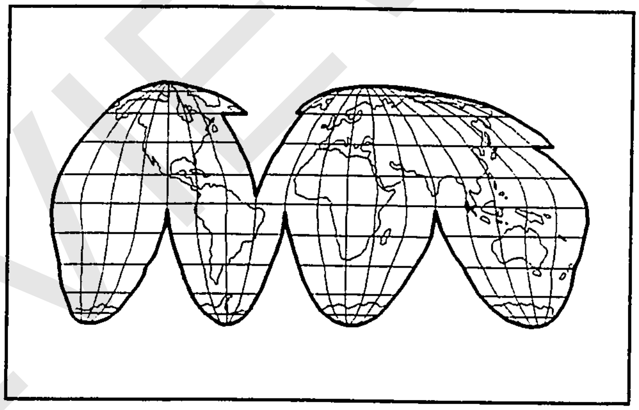
LIST OF FIGURES

CHAPTER 1

INTRODUCTION TO DESALINATION TECHNOLOGY AND THE EL PASO SOLAR POND

1.1 The Use of Solar Ponds for Desalination

As we enter the 21st century, the most viable solution for meeting an increasing world-wide fresh water shortage may well prove to be desalination - the process of removing salt from saltwater (such as from oceans and underground aquifers) to produce potable water. As the demand for natural, fresh drinking water continues to exceed the readily available supply, the need for desalination technology will likewise increase.



The two greatest obstacles traditionally associated with the desalination of water by distillation (or evaporation) are the large amounts of energy required to separate the water from the salt and proper disposal of the waste salts.

The energy required in a distillation process is provided either in the form of heat or electricity or a combination of both. In multieffect distillation, the energy requirement is typically 90% heat and 10% electricity (Figure 1.1). The heat is necessary to preheat the process water to a temperature such that it will boil when it enters the desalinator.

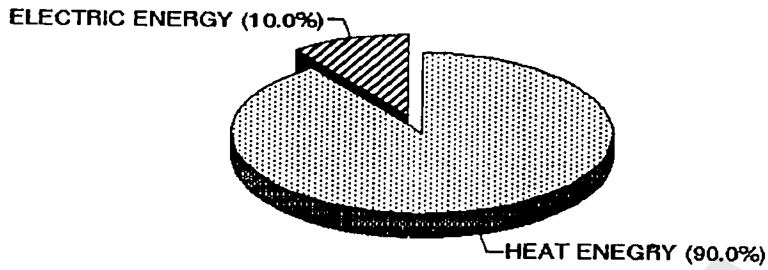


Figure 1.1
Heat Energy vs. Electric Energy Usage in
Typical Multistage Desalination System

Electricity is required to power electric motors, pumps, and controls for operating the system.

The operating cost of desalinating water by distillation therefore includes the cost of heat and electrical energies consumed. If a solar heat energy source is used, such as that provided through a salinity-gradient solar pond system (See Chapter 2 for description), for example, conventional energy consumption can be virtually eliminated. The use of solar pond-coupled desalting is also attractive since the temperature of the thermal energy needed for sub-atmospheric evaporation matches the temperature at which heat can be provided by a solar pond system.

Large amounts of salt are required to construct, maintain and expand a solar pond facility. This fact has important consequences when considering systems engineered for the

desalination of inland surface or ground waters. In desalinating sea water, the concentrated salt solution remaining following desalination can simply be returned to the sea. However for the desalination of inland waters the disposal of salt and reject brine is more complex. If dry salt can be produced and is of a quality that can be sold and if a market exists, some economic benefit might be gained from selling the salt. Typically this is not the case. Historically, at inland sites where industries produce brines, these have often been discarded in evaporation pits or injection wells. One example of such practices is provided by the West Texas oil industry. The environmental integrity of such practices is questionable and has become increasingly scrutinized. Disposal of brines is sometimes not economically viable, since costs associated with deep-well injection or removal through transportation for remote handling can be substantial. [Golding, 1991]

Solar ponds can provide an alternative tangible, managed repository for salts and brines at inland sites. When coupled with desalination technology, they offer a potentially attractive, unique system for economic fresh water production, while largely eliminating the problems and expense associated with salt disposal.

1.2 Selection of Promising Desalination Technology

In 1983, The University of Texas at El Paso Mechanical Engineering Department and the United States Bureau of

Reclamation constructed the El Paso Solar Pond in El Paso, Texas (See Chapter 2 for a description of how a solar pond works). The facility was established to study solar pond technology as a heat source to provide process heat, generate electricity, and desalinate brackish ground water.

The El Paso Solar Pond storage zone (having an area of approximately 2,000 m^2 and depth of 1 m)[1] was designed to produce hot brine (typically 90.5°C (195°F) in summer and 71.1°C (160°F) in winter) at a rate of up to 1,055,000 KJ/hr (1,000,000 BTU/hr). The U.S. Bureau of Reclamation requested contract bids from developers of promising new desalination technology to provide desalination equipment which would operate using this relatively low-temperature source of heat. It was specified that the desalination equipment be constructed, then installed at the El Paso facility, operate year-round on this low-temperature heat source, and produce 18.9 m^3/day (5,000 gal./day) of fresh water from brackish feed water.

The contract was awarded to W. L. Badger and Associates, a small company operated by a Chemical Engineer named Ferris Standiford. Mr. Standiford, with the support of Resources Conservation Company in Bellevue, Washington, built a prototype falling-film, multistage, flash evaporator and delivered it to El Paso in May, 1987. On June 24, 1987, Mr.

---

1 Old British Units (or English Units) will often be used in this thesis, since they are still commonly used in the U.S..

Standiford's "Spinflash" desalination unit produced fresh water from an artificial brackish feed supply at the rate of 17.4 m^3/day (4,600 gal./day) of fresh water, successfully demonstrating for the first time in the United States the coupling of solar ponds with desalination machinery. The unit was not to run unattended since a leak in the heat delivery system might possibly have caused solar pond brines to siphon out of the pond onto the surrounding ground. It therefore was only operated on an intermittent basis during the start-up phase.

1.3 Spinflash Technology and Process Description

Spinflash distillation technology was developed to produce fresh water from saltwater using a unique falling-film, multistage, flash evaporation process.

The following is a brief summary of the principles of operation, which are discussed in detail in the latest version of a Spinflash Operation and Maintenance Manual [Standiford 1987]. A schematic of the process is shown in Figure 1.2.

To start the process, saltwater is pumped from the saltwater source to the storage portion of the heat reject vessel. The saltwater is then pumped by a recirculation pump from this storage area to the cold sump at the top of the evaporator. This recirculation rate is adjusted by throttling a valve on the discharge side of the recirculation pump.

The saltwater is then heated as it falls down the inside

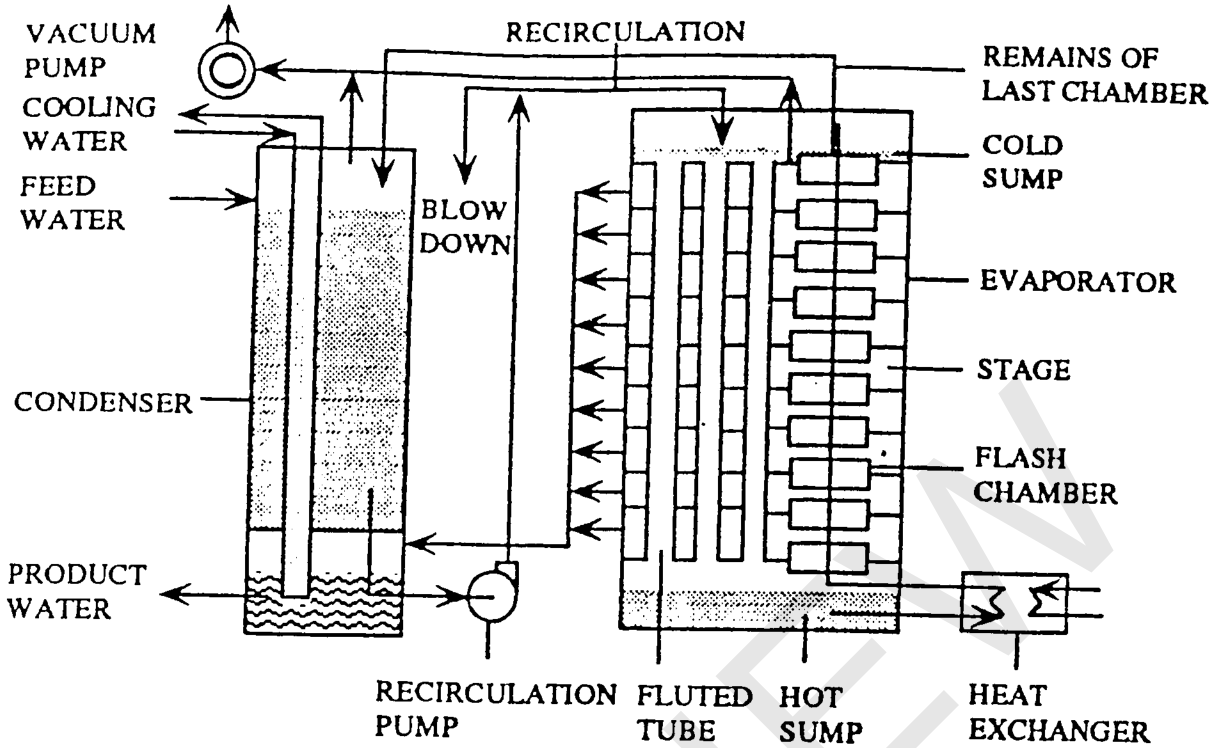


Figure 1.2
Spinflash Process Flow Schematic [Li, 1992]

walls of 54, two-inch diameter, aluminum fluted tubes. This preheated saltwater is collected in the hot sump at the bottom of the evaporator. The partially-heated saltwater is then drawn, under vacuum, through the heat exchanger where heat is added from the solar pond, through a hot sump level control valve, and into the first of 24 flash chambers. Here a partial vacuum, created by a vacuum pump, causes a small amount of the hot saltwater to evaporate or "flash", producing fresh water vapor.

The remaining saltwater is then pumped by rotating impellers up through the 24 flash chambers which operate at sequentially lower pressures and temperatures. The impellers aid in separating the water vapor from the liquid saltwater [Standiford 1987]. About one-tenth of the saltwater is

evaporated by the 24th flash chamber. The remaining saltwater returns to the storage portion of the reject vessel where saltwater makeup is added to replace the volume of water produced. The fresh water vapor which is produced in the 24 flash chambers is condensed on the outside of the 54 fluted vertical tubes. This condensing vapor releases its latent heat of vaporization to the aluminum fluted tubes which in turn heat the saltwater falling from the top (cold sump) to the bottom (hot sump) of the evaporator.

The condensed fresh water is collected, tested for purity, and in a commercial system would be ready for delivery. Salt is removed from the system by allowing a small amount of the recirculating saltwater to bleed off from the recirculation line, carrying the excess salt out of the system. This "bleed off", more commonly referred to as "blow down" is adjusted by a throttling a small valve, which varies the mass balance of the system. In our configuration, the bleed off rate was set for 0.5 gallons per minute. This resulted in an average mass balance as follows;

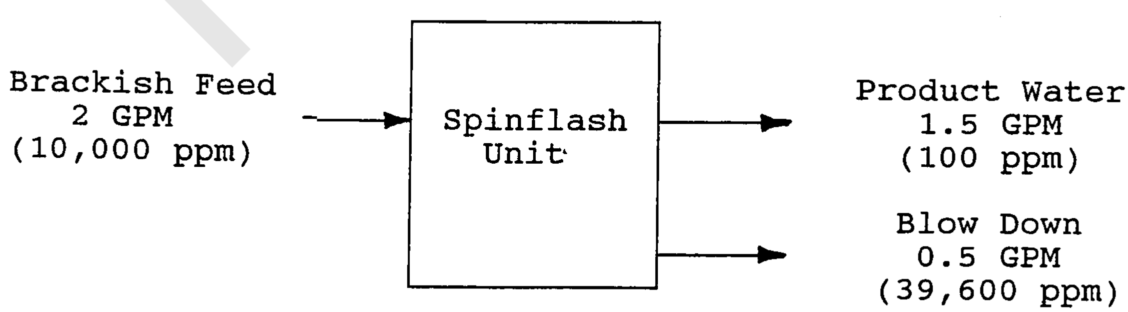


Figure 1.3
Spinflash Typical Mass Flow Schematic

When compared with other emerging technologies, the

Spinflash system offers the following benefits:

1) Small capacity unit
2) High production for given physical size
3) High thermal efficiency
4) Physically compact design occupying small space
5) Lightweight and transportable

And the following drawbacks:

1) Many moving parts
2) Difficult to manufacture
3) Difficult/impossible to repair internal leaks.

CHAPTER 2

INAUGURATION OF SPINFLASH OPERATION AT THE EL PASO SOLAR POND

2.1 Solar Pond Operation

a) How a Solar Pond Works

A solar pond is a body of saline water where solar energy is collected and stored in the form of heat. In operational solar ponds the water body characteristically consists of three main zones: The upper convective zone (UCZ), the middle zone, also known as the salinity-gradient zone (GZ), and the lower convective zone (LCZ) or storage zone.

As illustrated in Figure 2.1 the upper zone is convective, homogeneous and of low-salinity brine at low temperature. The middle zone is non-convective and acts as a

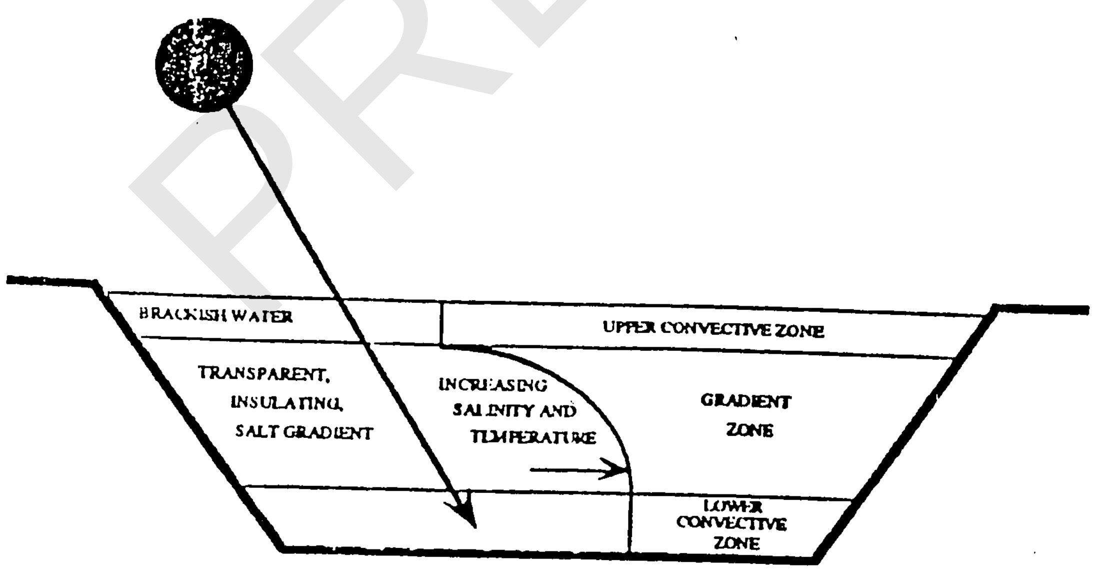


Figure 2.1
Solar Pond Cross Section [Li, 1992]

thermal insulator for tho heat stored in the lower convective zone. In the gradient zone both salinity and temperature increase with depth. The lower convective zone, which is characterized by the highest salinity and temperature brine, serves as a solar thermal storage zone. Incident solar radiation on the pond surface is collected via the surface area of the pond. The fraction of light that penetrates the surface travels through the water medium to the storage zone where it is trapped and transformed into heat. The amount of heat stored in the LCZ determines the thermal efficiency of a solar pond.

The El Paso Solar pond is a salinity-gradient pond composed of the three main zones, (UCZ, GZ, and LCZ). At this research, development and demonstration facility, hot brine pumped from the storage zone (LCZ) of the pond has been used to provide industrial process heat, power a Rankine cycle engine for generation of electricity and also supplies the heat energy necessary to operate the Spinflash multistage desalination unit.

Because heat produced in a solar pond relies solely on solar radiation, solar ponds are considered environmentally safe. They do not consume fossil fuel or radioactive elements, or expel pollutant gases or carbon emissions. As solar pond technology advances, solar ponds can be expected to become a commercially competitive alternative, renewable source of safe clean energy. [Abou-Chakra 1992].

b) Pond Experimental Program

The El Paso Solar Pond was established in 1985 and over the past seven years has been demonstrated to be an effective salinity-gradient pond technology. During this period, three applications have been studied which successfully utilize the heat generated by the solar pond [Swift 1991].

The pond is located on the facility of Bruce Foods, a Mexican food producer and cannery in the El Paso area. The usable heat provided by the pond has been delivered to various processes in the food plant in the form of process heat. Electricity has also been delivered by use of a Rankine-cycle heat engine, rated at 100 kilowatts, built and supplied by Ormat Turbines Ltd. of Israel. Additionally, heat has been delivered to the Spinflash desalination machine (the operation and performance of which are the subject of this thesis) to operate the unit and demonstrate the feasibility of desalinating brackish groundwaters. Included is the study of salt brine in the solar pond providing the heat source.

c) Brief Overview of Pond Temperature History

The history of the solar pond water temperatures (over the past five years) is shown in Figure 2.2. It can be seen that pond water storage temperature fluctuates throughout the year. A maximum temperature of 95°C was recorded in August 1991. A minimum temperature of 43°C was recorded in the storage zone in January 1989. The temperature over the past five years has averaged 73°C.

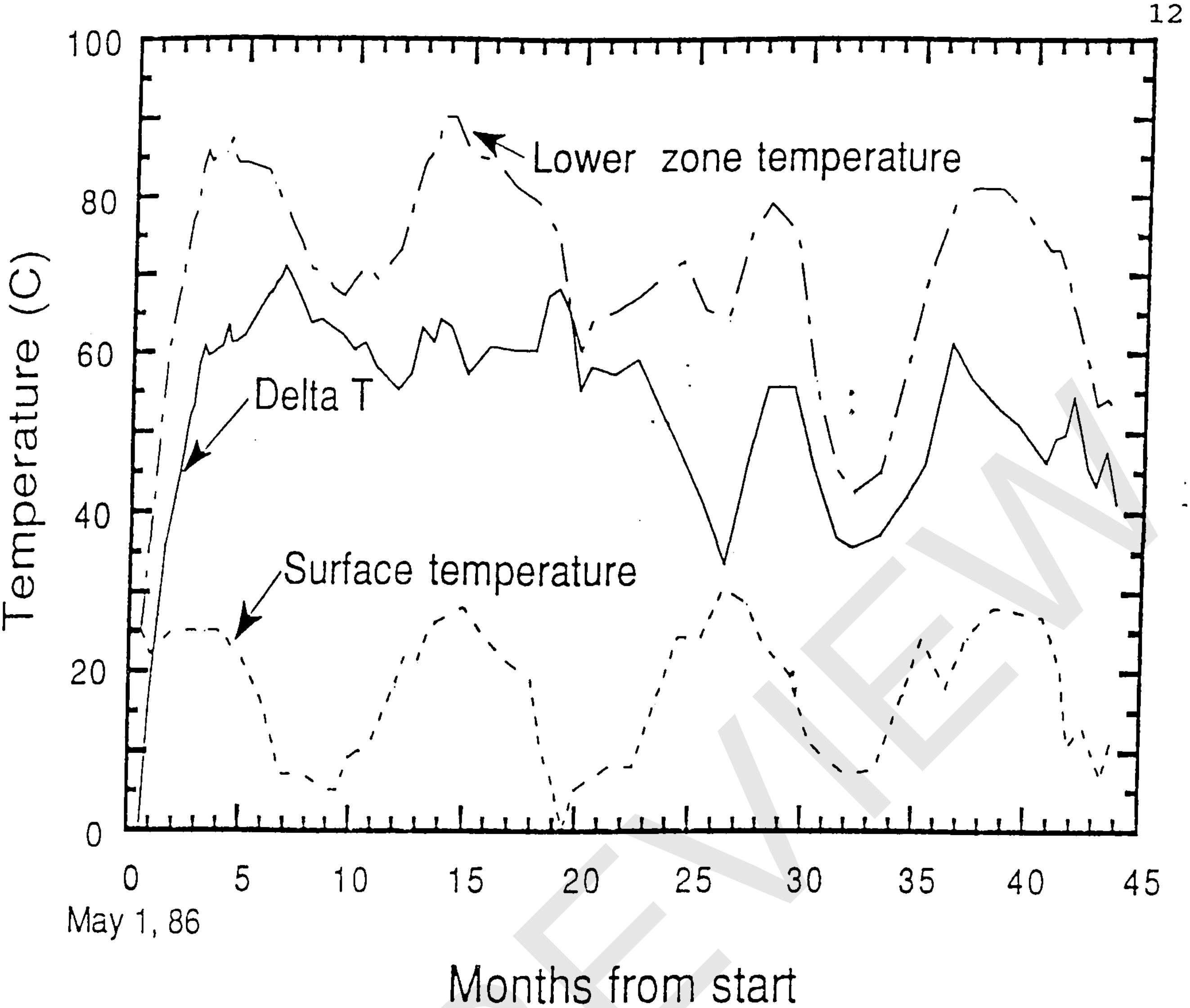


Figure 2.2
Temperature History of the El Paso Solar [Swift, 1990]

d) Overall Heat Delivery to the Spinflash

During the twelve-month test period throughout 1988, 36,376,400 kJ (34.48 million BTU's) of heat were extracted from the solar pond and delivered to the Spinflash desalination unit. Operating procedures related to the use of the Spinflash unit are described in Chapter 3.

2.2 Installation of the Spinflash Unit

The installation of the Spinflash unit on site next to