DEVELOPMENT OF A SIMPLE AND PRACTICAL METHOD TO MODIFY

THE STRUCTURE OF THE SALINITY GRADIENT OF A SOLAR POND

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ABSTRACT

A practical method for undertaking salinity-gradient modifications by injection in an operating solar pond is presented. The mixing process due to injection within salinity-gradient regions is first discussed, in order to demonstrate the magnitude and complexity of the mixing phenomena and processes. Fluid dynamic parameters such as densimetric Froude number are shown to be important to consider when planning injections. However, they have often not been taken carefully into account when undertaking injection-driven modifications at many research scale solar ponds, including the El Paso solar pond, in the past. Methods and procedures for making modifications within the salinity gradient are described and their recent application at the U.T. El Paso solar pond is used to illustrate successful implementation. Further research and testing is still needed, to ensure that the fundamentals of the mixing process (including that which occurs during scanning) result in an improved design of injection diffusers and associated control techniques. An Important aspect is the scale-up of mixing process as a function of pond size.

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INTRODUCTION.

1.1 Why Work on Developing Solar Pond Technology?

The recent accidents in nuclear technology make the necessity of finding new clean sources of renewable energy even more urgent, in order to supply the upcoming demand of energy for new generations. Nuclear energy has been shown to be very dangerous.

The Three Mile Island accident in 1979, in which the reactor practically melted, left behind contamination of the plant and some radiation was released to the surrounding area [1]. Subsequently in 1986, two large explosions destroyed one of four reactors at Chernobyl in the Soviet Union. Within days, high levels of radioactive fallout were detected in Europe. In two weeks, minor radioactivity was detected in Tokyo, Washington and throughout the northern hemisphere [2]. Several isotopes with half-lifes ranging from two hours to 24,000 years were released.

Two hundred and sixty six generations will now feel some effect of these accidents. The two most hazardous isotopes were Iodine 131 and Cesium 137, with a half life of 8 days and 30 years respectively; these two are chemically reactive elements that are readily absorbed into biological materials, thus contaminating our food chain [2]. Other isotopes such as Strontium-90 with a half-life of 27 years, and Plutonium-239, with a half-life of 24,000 years, were also released. If an accident of this magnitude was possible in these two countries, considered highly technological and developed, what is expected for a country with less technical resources when such events occur?

One obvious problem related to proliferation of nuclear technology is what might be termed "nuclear disinformation". General Electric, Westinghouse, and other

corporations in the USA, as well as other countries such as France, sell inherently dangerous nuclear technology to countries of the Third World; technologies as much as 30 years old! Such projects involve not only high costs for technology but most importantly they have inherently high risk: They are time bombs!

The investment and effort of the scientists of different countries could be better used for the development of their own more appropriate and safe technologies. They could, at least, be used to improve the already existent and constructed energy resource bases, and to avoid the depletion of the non-renewable resources of energy and the release of contamination to the environment. This thesis constitutes a personal contribution toward that goal.

1.2 Solar Pond Technology: Current Research and Development Context.

The research and development of solar pond technology has diminished in the USA since the early 1980's, perhaps due partly to the fact that it has been claimed that this technology was already commercial. The experience at the El Paso solar pond, coupled with knowledge of experimental programs elsewhere, has led to an awareness that much of the global pond technology is indeed immature.

Not surprisingly, then problems are still being confronted. The solar pond technology is site dependent, so most of the problems are derived from conditions specific to the site of construction and to the correspondent application, as well as the available resources at the site.

A substantial amount of work has been done by the international solar pond community [3]. Any country in which the conditions are suitable for solar pond technology can potentially benefit from the experience.

1.3 The Solar Pond as a Source of Energy.

The solar pond uses a clean and renewable source of energy. It employs the sun and natural elements such as soil, water, salt; and some off-the-shelf components in its construction. The advantage of the pond compared with other low-temperature solar alternatives, from the point of view of economics, is that the solar pond collects and stores energy conjunctionally.

A simple relation shows the effective rate of transformation from solar to thermal energy inside the pond storage region:

$$Q_{Th} = I_0 A \eta \tag{1.1}$$

where:

Q_{Th}- Thermal energy, W

I_0 - Incident solar radiation, W/m^2

A - Area of the pond, m^2

(at the lower interface, see Figure 1.1)

η - Coefficient of pond efficiency

(converting from solar energy to thermal energy)

As a source of energy solar ponds are limited to low temperatures of operation (45 to 90 ^{o}C) and a correspondingly low coefficient of efficiency. The conversion from solar to thermal energy typically gives a coefficient of efficiency in the order of 16 to 20%, and in the case of converting from solar energy to electricity the overall coefficient of efficiency is only around 2%! On this basis, the application of solar ponds is best for: low temperature industrial thermal processes; desalination,

agriculture (such as grain drying, greenhouse heating and cooling), ice production, food refrigeration, water pumping, salinity control, and the production of some chemical products, such as sodium sulfates [4]. Pasteurization, evaporative processes, food processing, textile processing, skin tanning, dyeing, and wool scouring are other recommended applications for solar pond technology [5]. Fish hatchery, mariculture, or shrimp growing applications are also currently being researched [6].

Solar ponds can currently be considered as an economical source of electricity generation for suppling energy in peak demand periods, and for remote applications where the actual cost of diesel-fuelled electricity generation is expensive.

1.4 The Solar Pond Configuration.

The body of a solar pond is composed of three zones: The Upper Convective Zone (UCZ), the Gradient Zone (GZ) and the Lower Convective Zone (LCZ). Figure 1.1 shows the physical configuration of a solar pond.

Each zone plays an important role in the operation of the pond. To achieve the best performance each of these zones must be maintained within certain dimensions (thickness) during pond operation. The range of engineering values for the thickness of the zones likely to be practical in solar pond operation are presented in Table I. The values come from existing ponds around the world, and from certain mathematical models like SOLPOND [7], GTPROFILE (developed by The University of Texas at EL Paso) and other models developed by institutions, such as the University of Queensland in Australia.

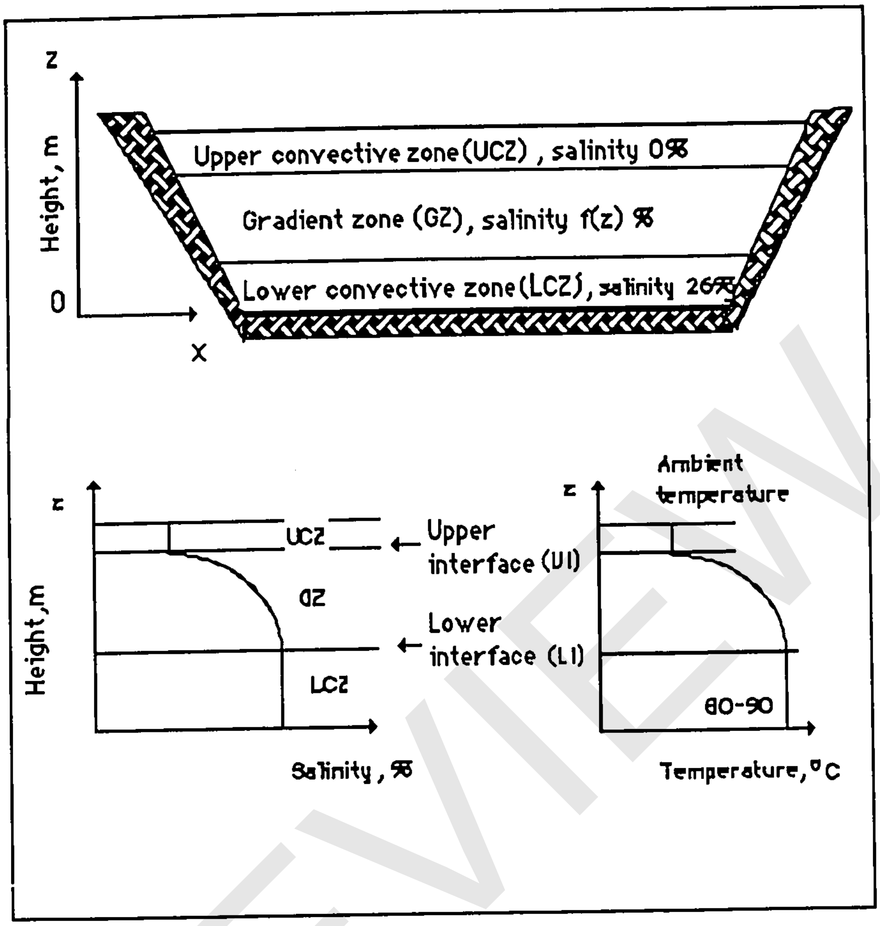

Figure 1.1 A schematic of the vertical profile of salinity and temperature gradients in a solar pond.

If a pond is to operate in a mode where energy is collected during seasons of abundant solar insolation and is to be stored for several weeks or even months, then a relatively deep LCZ is most favorable. If it is necessary to achieve high temperatures in a short time then the LCZ should be relatively shallow.

The practical depth of a solar pond is between 3.0 to 5.0 meters (theoretically a solar pond 10.0 m deep can be built).

TABLE 1.1 Characteristic zone widths for salinity-gradient solar ponds.

	Thickness, m
Upper Convective Zone, (UCZ)	~ 0.30 - 0.80
Gradient Zone Zone, (GZ)	~ 0.80 - 1.80
Lower Convective Zone (LCZ)	~ 0.50 - 3.0

The dimensions of a pond (the thickness of each zone and the initial salinity profile desired) are determined by doing a technical-economic analysis. The pond design is strongly influenced by the desired application.

1.5 The Dynamics of the Pond and the Need for Modifications to the Salinity Gradient.

Once the solar pond salinity gradient is established salt transport by diffusion from the bottom to the surface begins. Diffusion subtly but continuously induces profile change which then requires adjustments be made to maintain the initially established profile. A temperature-gradient profile is established simultaneously with the establishment of the salinity gradient. This temperature gradient also contributes to change the salinity structure of the pond, accelerating the transport of salt from the

LCZ to the UCZ. Figure 1.2 shows the natural tendency of the salinity gradient to change as a function of time.

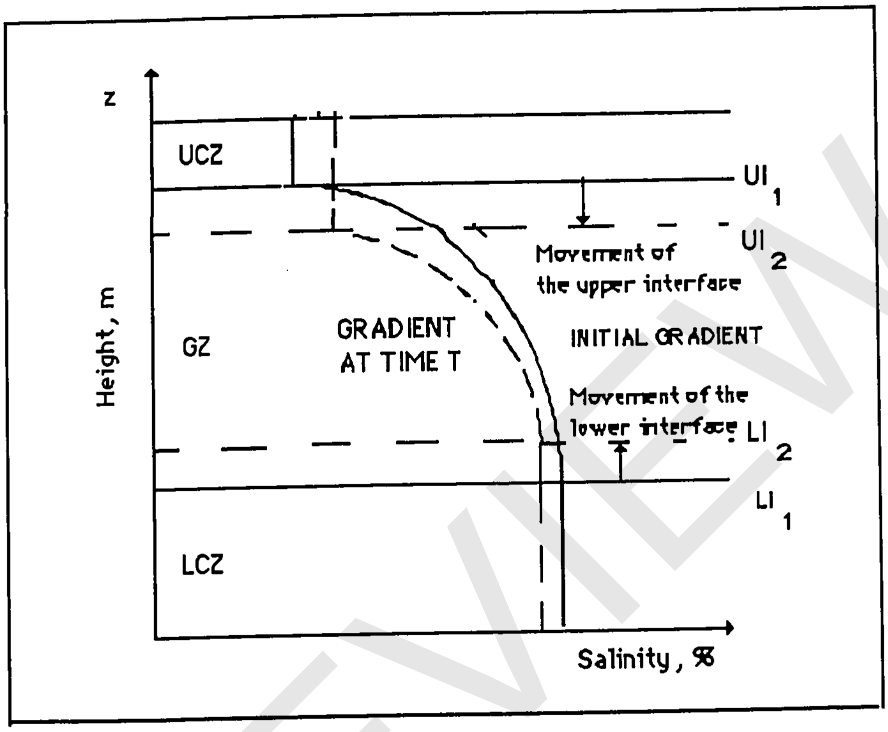

Figure 1.2 The natural evolution of the solar pond salinity gradient, when no externally induced modifications are made (such as injections).

If left to take their natural course, the time development of the gradient profiles brings about a critical (in terms of stability) situation either in the gradient region or near the interfaces. In other words, the non-convective nature of the gradient has a natural tendency to be eroded. The position of interfaces which physically exist in between the UCZ and the GZ, and between the GZ and LCZ will thus tend to move (see Figure 1.1).

An analysis of the stability margins within the main gradient can show the strength or weakness of local regions (see Zangrando [8]). Maintaining a high local stability

margin value (an internal stability margin of 2 was used for the case of the El Paso solar pond in 1988-90, as the minimum permissible stability margin value [9]) is necessary to assure the gradient region is maintained non-convective.

For maintenance or modification within the salinity gradient of the pond, sometimes it is necessary to inject high or low concentrated brine (See Figure 1.3).

1.6 Objective of this Work.

The main goal of this current work was to develop a simple and practical method to carry out modifications within the salinity gradient of a solar pond. The practical application of this method was achieved at the U.T. El Paso solar pond, and is reported here.

The content of this thesis is presented as follows:

Chapter 2 provides the theoretical basis for understanding the complicated phenomenon of the mixing process due to an injection into a stratified medium. The methods which can be used to maintain or modify the salinity gradient profile in a solar pond are then discussed (Chapter 3). In Chapter 4, the development of a simple method for practically modifying the gradient is introduced. Chapter 5 presents, the hardware required to implement the simple method. Then, in Chapter 6, some examples for the use of the methodology and hardware are presented. The results show that the method is effective in producing the desired changes in the salinity gradient profile. Additionally, certain guidelines for practical applications are suggested. The final Chapter presents conclusions and recommendations for further research on this topic.

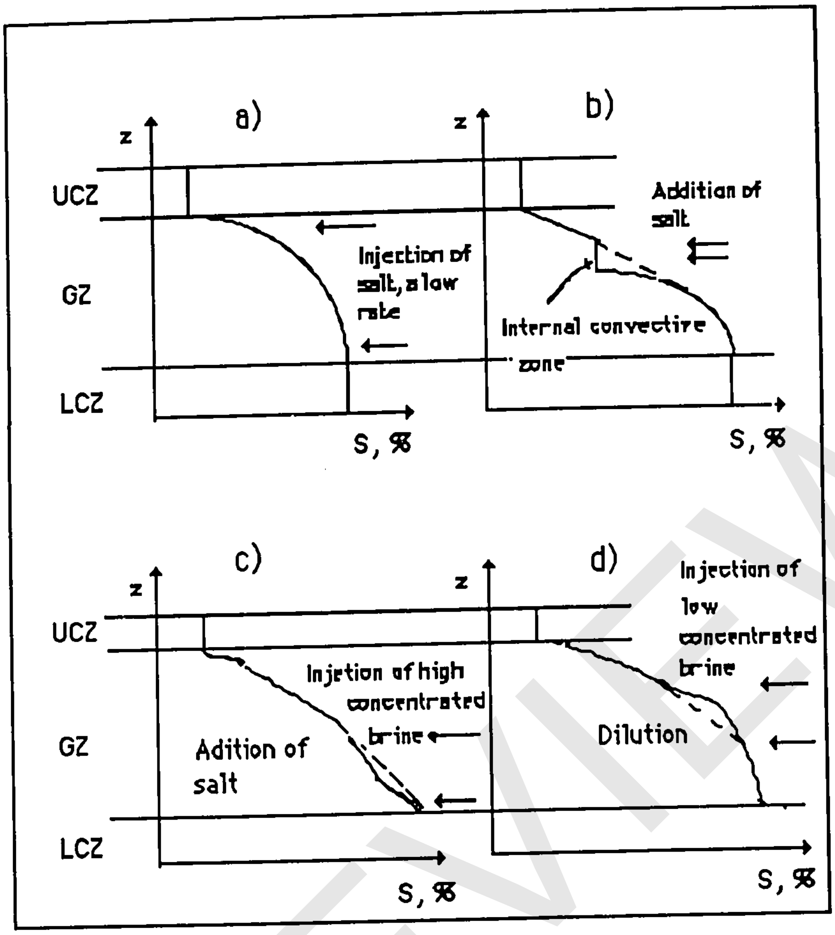

Figure 1.3 Examples of the kinds of adjustments in the salinity profile which are typically required to maintaini the salinity gradient profile in a solar pond: a) Upon continuous slow injection; b) Eliminating an internal convective region; c) and d) Altering the salinity profile shape (____ initial & - - - desired profile adjustment).