College of Engineering
Mechanical Engineering Department

Design of a Desalination Plant by Using Renewable Energy in the Southern of KSA

by
Team Members: 1. Wajdi W. Dosary 2. Mohamed H. Ayoub
3. Osama A. Zakri 4. Ismail A. Akish
5. Abdulrahman Aljayzani

PROJECT ADVISOR
Prof. Dr. Ahmed Sayed Ahmed Hassan
Dr. Ali Saeed Z. Al-Shahrani

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طلاب فريق العمل : 1.وجدى وليد دوسرى 2. محمد حسن أيوب
3. أسامه عبد الله زكرى 4. اسماعيل أحمد عاكش
5. عبد الرحمن محمد الجيزانى

مشرفو المشروع : أ.د. أحمد سيد حسن د. على سعيد الشهرانى

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Design of a Desalination Plant by Using Renewable Energy in the Southern of KSA

APPROVAL RECOMMENDED:

Examination Committee:

Assoc. Prof. Dr. Salem M. Abdelsamad
Dr. Ahmed H. Abdelkareem
Professor Dr. Ahmed Sayed A. Hassan
Dr. Ali Saeed Z. Al-Shahrani

PROJECT SUPERVISORS

Professor Dr. Ahmed Sayed A. Hassan
Dr. Ali Saeed Z. Al-Shahrani

DATE: June, 2014

DEPARTMENT HEAD

Dr. Ali Saeed Z. Al-Shahrani

COURSE INSTRUCTOR

APPROVED:

DEAN, COLLEGE OF ENGINEERING

Dr. Mohamed Almagrabe

(1435-2014)

ABSTRACT

Design of a Desalination Plant by Using Renewable Energy in the Southern of KSA

Senior project submitted to the department of Mechanical Engineering

Saudi Arabia as a part of Arabian Peninsula is rich in renewable energy especially solar and wind. Jazan province, located at the southern-west region, occupies one of the top regions in these renewable resources. Therefore, the investment in renewable energy in this region has several advantages. Jazan Economic City (JEC) is one of these advantages, for which two-thirds of the city has been allocated for heavy industries and other opportunities of different secondary industries. The manpower of these industries is in need for distilled water for their public utilities. Therefore, water desalination could be one of the promising industries which may be added to JEC to supply soft water for public.

The solar energy as renewable energy resources for desalination of water is novel, since it allows the daily use of renewable resources existed.

Three phases are employed for desalination process. The first phase is preheating the pumped seawater by means of solar pond and flat plate collector, this is followed by steam generation phase by means of parabolic dish or trough collectors. The third phase is the condensation phase. An automatic sun tracking system is attached to parabolic dish or trough collector to increase the efficiency of solar energy collected during the day.

Preliminary calculations suggest that the system could provide a temperature of 315 oC at least during the day with about 0.06 liter/sec of soft water, using parabolic dish of 4 m2 surface area.

DEDICATION

To my father, who through his financial and moral support was the source of inspiration and the mainstay in my attaining an education, I dedicate this project.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Symbols	DESCRIPTION	UNITS
A —	Area, m^2	
AOD —	Amount of distillate, liter /h m^2	
a_1 ,a_2, a_3,a_4 —	Constants	
C —	Capacity, m^3	
Cp —	Specific heat, J/kgK	
D —	Diameter, m	
d_{ncz} —	Vertical extent of non-convective zone, m	
d_t —	Time interval, s	
g —	Gravity acceleration, m^2/s	
H —	High, m	
h —	Heat transfer coefficient, W/m^2K	
h_{ba} —	Heat transfer coefficient, W/m^2K	
$h_{c,\ c\text{-}a}$ —	Coefficient of convective heat transfer bet. cover and air, W/m^2K	
$h_{c,p\text{-}a}$ —	Coefficient of convective heat transfer bet. plate and air, W/m^2K	
h_{fg} —	Latent heat of evaporation, J/kg	
$h_{r,p\text{-}c}$ —	Coefficient of radiation heat transfer bet. plate and cover, W/m^2K h(z)	
I —	Incident solar radiation or solar flux on an inclined collector, W/m^2	
I_g —	Global radiation intensity on a horizontal plate, W/m^2	

I_d — Diffuse radiation intensity on a horizontal plane, W/m^2

k — Thermal conductivity of air, W/mK

Kw — Stored water's thermal conductivity, W/mK

LCZ — Solar pond lower convective zone

m_c — Condensate

m_p — Mass of water in pond, kg

m_w — Mass of water in the still, kg

NCZ — Solar pond non-convective zone

P — Pressure, N/m^2

P — Power, w

Q — Heat, KJ

q — Heat flux, W/m^2

s — Salinity, g/kg

T — Temperature, **°C**

T_{amb} — Ambient temperature, **°C**

T_{sky} — Temperature of sky, **°C**

t — Time, s

UCZ — Solar pond upper convective zone

U_b — Bottom heat loss coefficient, W/m^2K

U_c — Cover heat loss coefficient, W/m^2K

Greek

g — Emissivity

α — Absorptivity

φ — Latitude, degrees

δ — Declination, degrees

β — Collector surface inclination, degrees

σ — Stefan-Boltzmann constant, W/m^2K^4

ω — Hour angle, degrees

Subscripts

a — Ambient

b — Basin

c — Convective

d — Diffuse

e — Evaporative

eff — Equivalent

g — Glass

p — Pond

r — Radiative

s — Surface

t — Time, s

w — Water

CHAPTER I

INTRODUCTION

To date few countries have renewable fresh water resources that are well above the threshold of 1000 cubic meters per capita per year, which is considered as demarcation line of water poverty. With a population expected to be doubling until 2050, the Middle East & North Africa (MENA) region would be facing a serious water crisis, if it would remain relying only on the available natural renewable freshwater resources. Arabian Peninsula, especially in Saudi Arabia, suffers from increasing demand of fresh water and the limited availability of natural water resources [1]. This gap between demand and request is expected to widen dramatically in the near future, especially at Jazan province, due to the existence of Jazan Economic City (JEC). The high rate of population growth expected and the improvement in the standard living required need a large quantity of fresh water. Desalination of seawater and brackish water is one possible solution to safeguard supplying of fresh water, so that the tap does not run dry. Moreover, drinking water of acceptable quality has become a scarce commodity and only brackish or seawater is available.

The water shortage problem is not only exclusive to developing countries, but also appears frequently in certain regions of the developed countries due to seasonal episodes of drought. In general, the production capacity of desalination facilities reaches about 26.5 million cubic per day [2]. There are two main technologies which are applied on a commercial scale; they are thermal distillation processes and membrane processes. Thermal desalination may include Multi Stage Flash (MSF), Multi-Effect Distillation (MED), and Vapor Compression (VC), however membrane desalination may include Reverse Osmosis (RO) and Electro-Dialysis (ED). The dominant processes are MSF and RO, from thermal and membrane desalination, respectively. The MSF process represents more than 93% of the thermal process production, whereas RO process represents more than 88% of membrane processes production [3, 4]. Practically, multi stage thermal distillation acquires up to 80% of the market, for which such plants uses fossil-fuel as an energy source [5].

The use of renewable energy, especially solar, in desalination of seawater is a subject of many investigations during the last years, e.g. [6 - 8]. The present project proposes the development of thermal desalination plant, using solar energy source. Since the basic principle of thermal process depends on phase transition by energy addition or removal to separate fresh water from saline water. The work suggests building a small-scale of solar desalination system. The first phase of the plant, the pumped seawater is preheated by means of both solar pond and flat plate collector; it is expected to reach 90 Celsius at the end of this phase. Then a parabolic dish collector will be used in the second phase for steam generation. The whole system will include all the necessary pipes, valves, tanks, and pumps. The system is supplied with solar tracking system for the parabolic dish collector.

1-1 Literature Review

Renewable energy technologies show great promise for water desalination [9 -12]. These energy technologies driven desalination systems fall into two categories. The first includes distillation processes driven by heat produced directly by the renewable energy system, while the second includes membrane and distillation processes driven by electricity or mechanical energy produced. With the world's fresh water demands increasing, much research has been directed at addressing the challenges in using renewable energy to meet the power needs for desalination plants [13].

Seawater desalination based on renewable energy, using solar heat, is promising desalination process. The desalination plant is referred to as an indirect process if the heat comes from a separate solar collector or solar ponds; whereas it is referred to as direct if all components are integrated into the desalination plant [14]. Particularly attractive is desalination associated with concentrating solar power (CSP) plants. CSP plants collect solar radiation and provide high-temperature heat for electricity generation. Therefore, they can be associated with either membrane desalination units, e.g. reverse osmosis (RO), or thermal desalination units. CSP plants are often equipped with thermal storage systems to extend operation when solar radiation is not available, and/or combined with conventional power plants for hybrid operation. This paves the way to a number of design solutions which combine electricity and heat generation with water desalination via either thermal or membrane separation processes. CSP plants are also large enough to provide core energy for medium- to large-scale seawater desalination. In desert regions (e.g. MENA) with high direct solar irradiance, CSP is considered a promising multi-purpose technology for electricity, heat and district cooling production, and water desalination. Solar desalination systems have low operation and maintenance costs but require large installation areas and high initial investments.

However, concentrating solar power (CSP) offers a sustainable alternative to fossil fuels for large scale seawater desalination. CSP can help to solve the problem especially in Middle East and North Africa, but market introduction must start immediately in order to achieve the necessary freshwater production rates in time [15]. Most of such technologies have already been demonstrated, except for Solar/CSP-MED. With the rapid decrease of renewable energy costs, technical advances and increasing number of installations, renewable desalination is likely to reduce significantly its cost in the near future and become an important source of water supply for regions affected by water scarcity. Attention has been directed towards improving the efficiencies of the solar energy conversions, desalination technologies and their optimal coupling to make them economically viable for small and medium scale applications. Solar energy can be used directly as thermal or it can be converted to electrical energy to drive reverse osmosis units. The thermal energy can be achieved in solar stills, collectors, or solar ponds. However, electrical energy can be produced from solar energy directly by photo-voltaic (PV) conversion or via a solar thermal power plant.

The electrical and mechanical power generated by a wind turbine can be used to power desalination plants, notably RO and ED desalination units, and vapor compression (VC) distillation process, particularly Mechanical Vapor Compression (MVC). In the MVC, the mechanical energy of the wind turbine is used directly for VC without further conversion into electricity. In general, wind power based desalination can be one of the most promising options for seawater desalination, especially in coastal areas with high wind potential. Water desalination itself can provide an excellent storage opportunity in the case of electricity generation exceeding the demand [16]. The cost of desalination is largely dominated by the energy cost. Therefore, the economic feasibility of desalination depends strongly on local availability and cost of energy. Comparisons between different desalination technologies should be based on identical local conditions. They include feed-water transportation, fresh water delivery to end-users, brine disposal and the size of the plant. As far as capital, and operation and maintenance cost is concerned, a comparison of two most used conventional desalination systems, RO and MSF installed in Libya, shows that the MSF plant requires higher capital costs while the RO plant requires higher operation and maintenance costs due to the plant complexity [17].

However, concentrating solar power (CSP) is a unique renewable energy technology. CSP systems have the ability to provide electricity, refrigeration and water purification in one unit. This technology will be extremely helpful in improving the quality of life for many people around the world who lack the energy needed to live a healthy life. Sunlight shining on the curved glass is concentrated to a small point. When all the heat energy that was spread across the surface of the magnifying glass is focused to a single point, the result is a dramatic rise in temperature. This is considered the beginning of modern solar concentration. Direct steam generation (DSG) can be a more efficient and economic way of producing steam from solar collectors.

1-1.1 Solar Ponds

A solar pond is a simple and low cost solar energy system which collects solar radiation and stores it as thermal energy in the same medium for a long period of time. For this reason, solar ponds attract the interest of researchers in this subject more than some alternative solar energy systems.

1.1.1.1 Physics of the solar ponds

Solar ponds generally consist of three regions, the upper convective zone (UCZ), the non-convective zone (NCZ) and the lower convective zone (LCZ), as shown in figure. 1. The UCZ is the topmost layer of the solar pond. It is a relatively thin layer which consists almost wholly of fresh water. The NCZ is just below the UCZ and has an increasing concentration relative to the UCZ, and it also acts as an insulation on the LCZ. The LCZ is the layer in which the salt concentration is the greatest, and there is no concentration gradient in it as shown in Figure 1. If the concentration gradient of the NCZ is great enough, no convective motion will occur in this region, and the energy absorbed in the bottom of the pond will be stored in the LCZ. Water is a fluid which does not transmit infrared radiation, so only the visible light part of the solar energy spectrum reaches the bottom of the pond and is absorbed there. Because of the poor conductive capability of water, the nature of infrared radiation and the insulating property of the NCZ, the stored energy in the LCZ only escapes from the pond with conduction. So, this action provides the solar pond as a collector at the same time as being a heat storage device [1±4].

The principle and application potential of solar ponds were reported in the literature at the beginning of this century. The observed temperatures increasing up to 70^{o}C at a depth of around 1.32 m during the end of summer. The minimum temperature was 26^{o}C during early spring [18]. These high temperatures were apparently due to the salinity gradient in the lake. Thereafter, natural temperature gradients occurring in lakes were reported in a number of countries. Anderson reported on a shallow saline lake in Washington State, showing temperatures up to 508Cin midsummer at a depth of 2 m.

A salinity-gradient solar pond (SGSP) is a combined solar energy collector and heat storage system reliant upon an aqueous solution of salt at varying densities to suppress natural convection and store thermal energy (Hull et al.,1988). The SGSP consists of three different zones; the upper convective zone (UCZ) with uniform low salinity; a non-convective zone (NCZ) with a gradually increasing density; and a lower convective zone (LCZ), called the storage zone, having uniform density as shown in figure 1.

A solar pond is a solar thermal collector and storage system which is essentially a water pool with suppressed heat losses. It can supply heat up to a temperature of approximately 95^{O}C. The Solar pond involves simple technology and uses water as working material for collection of solar radiant energy and its conversion to heat, storage of heat and transport of thermal energy out of the system.

Solar pond technology inhibits heat loss mechanisms by dissolving salt into the bottom layer of the pond, making it too heavy to rise to the surface, even when hot. The salt concentration increases with depth, thereby forming a salinity gradient. The solar energy which reaches the bottom of the pond remains entrapped there. The useful thermal energy is then withdrawn from the solar pond in the form of hot brine. The pre-requisites for establishing solar ponds are: a large tract of land, solar radiation, and cheaply available salt such as Sodium Chloride or bittern.

A salt gradient solar pond is an efficient, low cost solar energy collection and long range storage system for low temperature heat. In a salinity gradient solar pond, the concentration of salt dissolved in the water increases with depth. It is important to maintain the clarity of a solar pond to allow as much solar radiation as possible to reach the lower zone. The stability of its salinity gradient must also be maintained for it to perform efficiently as a store of solar energy. Water clarity is essential for high performance of solar ponds.

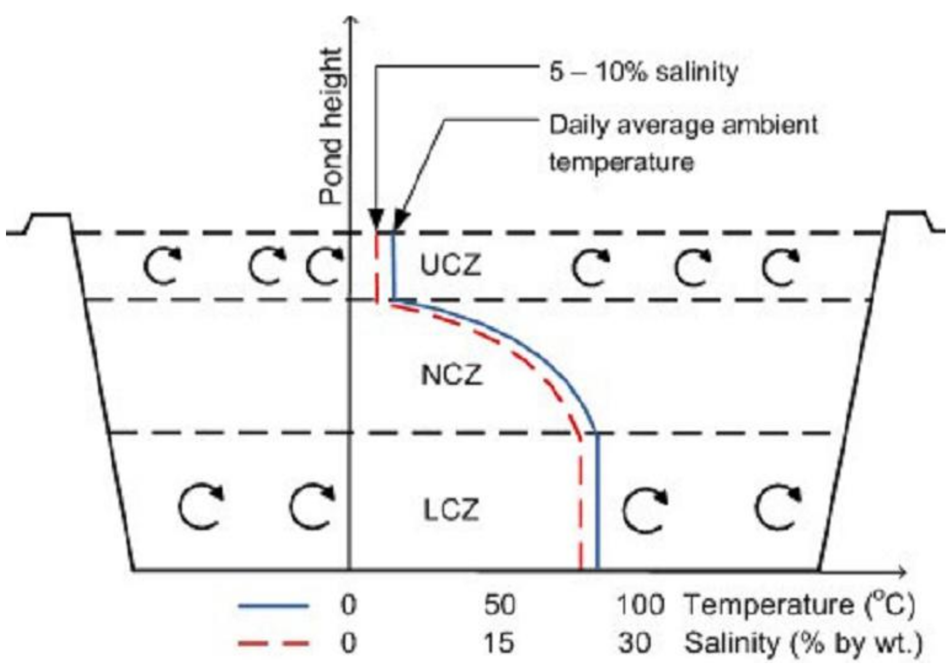

Fig. 1: Schematic of a salt gradient solar pond

1.1.1.2 The Upper Convective Zone

An upper convective zone consists of clear fresh water which acts as a solar collector or receiver and has relatively small depth and is generally close to ambient temperature. The upper convective zone is the primary site where external environmental influences impinge upon the pond. The upper convective zone is influenced by wind agitation and convective mixing. Its thickness is between 0.2-0.5 m and its salinity ranges from 2% to 80%. The upper convective zone is a zone of absorption and transmission.

1.1.1.3 The Non-Convective Zone

The non-convective zone has a salt gradient, is much thicker than the upper convective zone and occupies more than half the depth of the pond. Salt concentration and temperature increase with depth. The non-convective zone separates the upper and lower convective zones and that possess several different salt concentration layers, constituting a salinity gradient. The main focus of concern for the gradient zone is on its internal stability. A solar pond cannot operate without an internally stable salinity gradient and, as part of a minimum requirement; density must either be uniform or increase downwards to prevent any gravitational overturn. This means that the salt concentration must increase downwards as well.

Instability of a solar pond is usually linked to a weak salt gradient, commonly because of a gradient breakdown. Due to its unique makeup, the gradient zone acts primarily as insulation so that little energy is lost when solar radiation is transmitted through the surface zone and the gradient zone and stored in the lower convective zone.

1.1.1.4 The Lower Convective Zone

The lower convective zone has high salt concentration and serves as the heat storage zone. Almost as thick as the middle non-convective zone, salt concentration and temperatures are nearly constant in this zone. The lower convective zone is normally the region in which useful heat is stored and from which it is extracted. Most of the heat removed derives from heat provided by solar energy either absorbed in the volume of pond water or the floor of the pond. Heat removal can be accomplished by extracting brine or usually by passing it through an external heat exchanger.

The lower convective zone is a homogeneous, concentrated salt solution that can be either convecting or temperature stratified. Above it the non-convective gradient zone constitutes a thermal insulation layer that contains a salinity gradient. Unlike the surface zone, transparency in the lower convective zone does not have as much influence on the thermal performance of the solar pond, poor transparency resulting mostly from dirt from the bottom of the pond stirred up by circulation in the lower region. The simplicity of the solar pond and its capability of generating sustainable heat above 60^0C makes it attractive for a lot of applications. The energy stored and collected in a solar pond is low grade heat at temperatures limited by the boiling point of the bottom zone brine.

1.1.1.5 Pyramid Hill Solar pond

In 2000- 2001, a solar pond project was set up at Pyramid Hill Salt Pty Ltd. It is a collaborative project involving RMIT University, with two industry partners; Geo- Eng Australia Pty Ltd and Pyramid Salt Pty Ltd. The Project was supported by funding from the Australian Greenhouse Office under the Renewable Energy Commercialization Program. The project focused on the use of solar ponds for industrial process heating and in particular for the drying process in commercial salt production. The pond is located in northern Victoria and is approximately 200 km north of Melbourne on the Pyramid Hill - Boort Road as shown in Figure 2. This 3000 square meter solar pond supplies up to 60 KW of process heat for commercial salt production. This demonstration facility is a good example of a solar pond designed for a specific application.

Fig. 2: Demonstration solar Pond at Pyramid Hill in Northern Victoria

1.1.1.6 Clarity maintenance of the solar ponds

In the context of solar ponds, the term clarity is used to characterize the ability of the brine above the storage zone to transmit solar radiation to the storage zone. Clarity of pond water is one of the most important factors in achieving high performance and stability. It is important to maintain the clarity of a solar pond to allow as much solar radiation as possible to reach the lower zone. The more radiation that can penetrate to the storage zone, the higher will be the collection efficiency of the pond. Chemical treatment of solar pond brine is necessary to control bacteria, algae, and mineral content for good transmissivity. Water clarity, quantified in terms of the turbidity level, plays a critical role in the magnitude of insolation, with the effect of turbidity on solar penetration increasing with the depth of water [19].

Brine clarity in a solar pond is important as it affects the amount of radiation reaching the LCZ. In order to maximize the thermal performance of the pond, the transparency needs to be maintained. More radiation penetrating through to the storage zone results in higher collection efficiency of the solar pond. It is important that the salt gradient zone be kept as clear as possible within reasonable economic limits. Pond clarity monitoring and maintenance are important factors for good thermal performance and stability. Thermal performance of solar ponds critically depends on high transparency of the pond brine to solar radiation. Impairment of transparency may arise from dissolved colored substances, suspended particles, or populations of algae and bacteria. The chemical composition of solar pond brines varies greatly, and the quality of makeup water and type of airborne debris entering the pond is highly site specific. Brine clarity requires regular maintenance specific to each brine and site.

1.1.1.6.1 Chemical Method

Different methods and chemicals have been applied in various solar ponds for maintaining clarity. Many are adapted from standard swimming pool procedures. Copper compounds, chlorination and acidification are the principal chemical methods applied in various solar ponds.

1.1.1.6.2 Chlorination

Chlorination is one of the most widely used methods to control algal and microbial populations in solar ponds.

1.1.1.7 Salt Management

The natural tendency for salt to diffuse upwards is from higher concentration to lower concentration. If the solar pond is left unattended, the salt from the storage zone will diffuse upwards and destroy the gradient zone. The amount of salt necessary to maintain the salt gradient in the insulating layer will depend on the depth of the layer, type of salt used, and the temperature gradient across the layer. Salt will slowly diffuse upwards through the insulating layer, thereby degrading the salt gradient. To maintain the salt gradient, salt must be added to the bottom of the pond and the surface flushed with fresh water. Sodium chloride (NaCl) salt was filled in the salt charger of the Bundoora (NaCl) pond at intermittent levels. In terms of pond area it works out to 67 $gm/m^2/day$. Salt consumption of the pond was highest in summer and it was lower during the other seasons.

1.1.1.7.1 Salt Charging in a solar pond

There are two methods of salt charging:

1. Salt charger - salt injection at the bottom through the charger,
2. Diffuser method - a liquid with higher salt concentration is injected at the lower interface.

The rate of brine injection (m_s) can be calculated by the following formula:

$m_s = V_C*C_{in}$

Where V_C is the volumetric flow rate of the concentrated brine C_{in} is the concentration of the incoming brine.

1.1.1.8 Solar Pond Description

This pond is 4.4 m in diameter and 15 square meters in area as shown in Fig. 3. Its wall and base are made of high density plastic with a thickness of 0.011 m. The base of the solar pond is insulated with 0.1 m of Styrofoam. The level of water in the pond is fixed at 1.84 m from the bottom using an overflow system. The pond base is 1.02 m below the ground level. In this pond, bittern, which is a by-product of evaporated saltwater in the manufacture of sodium chloride, was used to build the salinity gradient. Bittern also occurs naturally in and under salt lakes in Australia. Bittern has sodium chloride (NaCl) and magnesium chloride (MgCl2) as its main constituents. The main benefits of bitterns are that they provide a high-density solution which enables a very stable salinity gradient and they are widely available at low cost. The surface washing system for the pond is shown in Figure 3, and the flushing arrangements at Magnesium chloride pond is shown in Figure 4.

Fig. 3: RMIT Magnesium Chloride solar pond

Fig. 4: Flushing arrangements at Magnesium chloride pond

1.1.1.9 Operation of solar ponds

For the operation of solar ponds, periodic observations of basic parameters are necessary in order to monitor and predict the pond performance.

1.1.2 Solar Collectors without concentration (Flat plate collectors)

These collectors are characterized by not having methodic concentration of solar energy, so that the relationship between the collector and the surface is almost the absorption unit. Generally, flat-plate collector acts as a receptor that gathers energy from the sun and warm up a plate. The energy stored in the plate is transferred to the fluid. Usually, these collectors have a transparent cover glass or plastic taking advantage of the greenhouse effect, consisting of a series of copper tubes, which exposed to the sun absorb solar radiation and it is transmitted to the fluid passing through its interior. Its application is the production of hot water, air conditioning and heating of swimming pools.

One type of flat plate collector is called air Collectors: Its main feature is to have the air as a heat carrier fluid. They have a maximum temperature limit and work better for a normal road, but in contrast with a low heat capacity. Another type of flat plate collector which is called a vacuum collector: Those have a double deck envelope, sealed, insulated inside and outside. They are more expensive, in addition to losing the effect of vacuum with the passage of time. The third type is called heat-tubes flat plate collector. This type has a cylindrical symmetry, consisting of two concentric tubes; a glass exterior and one interior painted with black paint or selectively. The fluid flows through the internal tube which is used in the heating application. Figure 5 shows the flat plate collector type, while figure 6 shows flat plate collector with hot water storage tank.

Fig.5: Flat plate collector type

Fig. 6: Flat plate collector with hot water storage tank

Solar collectors, in particular flat panel solar collectors, are well-known devices which are usually used to absorb and transfer solar energy into a collection fluid. Principally, solar collectors consist of a blackened absorbing cylinder or plate contained in a housing which is frontally closed by a transparent window panel. Due to the diluted nature of solar light, in order to increase the operating temperature by reducing the thermal losses, solar collectors may be evacuated during use to eliminate gas convection and molecular conduction. Very high temperatures could also be achieved by light focusing. However, only direct light is focused, while diffuse light is lost. Figure 7 shows the high temperature type of flat plate solar collector as mentioned.

Fig. 7: High temperature type of flat plate solar collector

1.1.2.1 Unglazed flat-plate collectors

Unglazed flat plate collectors are the most common type and cheaper than other types of collectors. They are the simplest types of collectors; water passes through dark tubes or sacks that absorb sunlight without any glass or plastic cover. Figure 10 shows unglazed liquid flat-plate collectors, which in are usually made of a black polymer. They do not have a selective coating and do not include a frame and insulation at the back; they are usually simply laid on a roof or on a wooden support. Unglazed collectors are commonly used for applications requiring energy delivery at low temperatures. Figure 8a shows the tube on sheet for unglazed liquid flat-plate collectors, while Fig. 8b shows a plastic pipe on unglazed liquid flat-plate collectors.

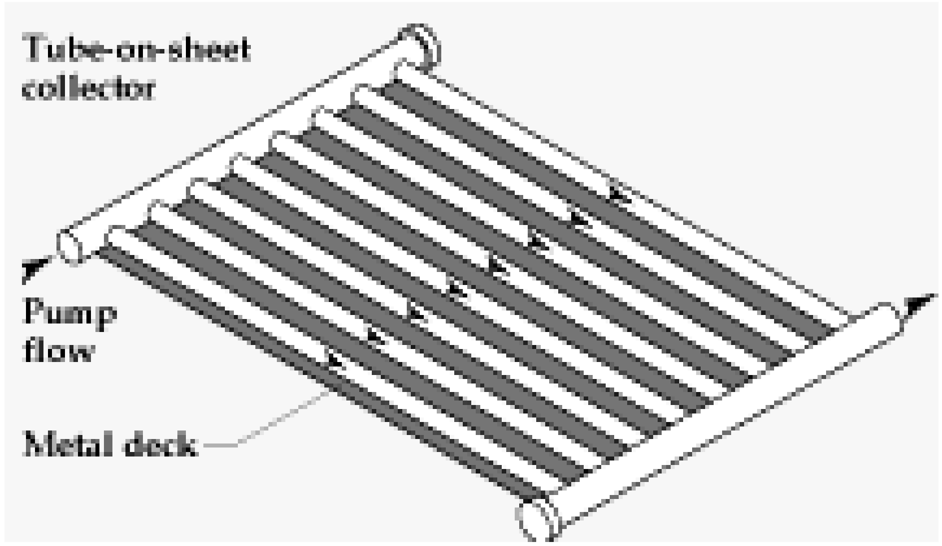

Fig. 8a: Unglazed liquid flat-plate collectors

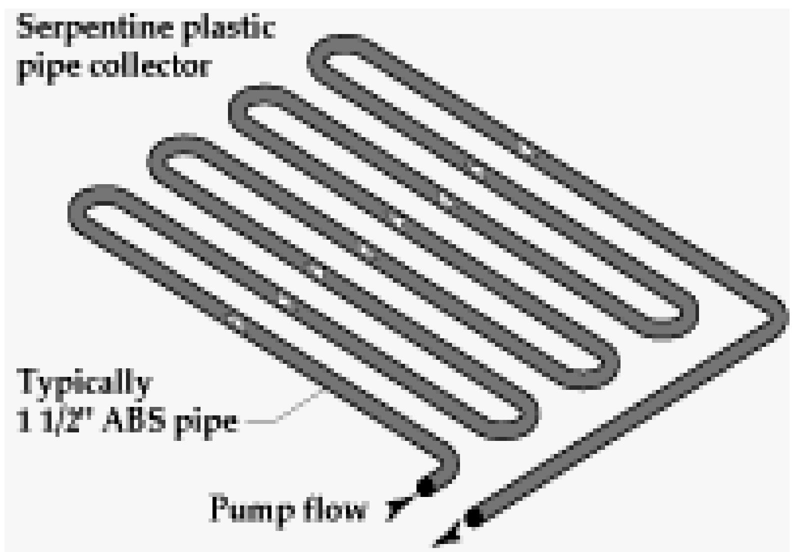

Fig. 8b: Plastic pipe on unglazed liquid flat-plate collectors

1.1.2.2 Glazed Flat-Plate Solar Collectors

Glazed flat-plate collectors consist of one or more sheets of glass which help trap solar heat. These types of collectors are essentially squat as shown in Figure 9. The translucent top, or “glazing,” is designed to let sunlight in while preventing heat energy from getting out. The bottom of the collector is a black surface designed to absorb sunlight and release the energy as heat, which is in turn absorbed by the water and trapped by the glazing. Water flows into a lower corner of the collector and becomes heated before exiting through a higher corner. The insulation provided by the glazing allows flat plate collectors to heat water as much as 55˚C above the surrounding air temperature, depending on the angle of the sun, the exact design of the collector, and other factors.

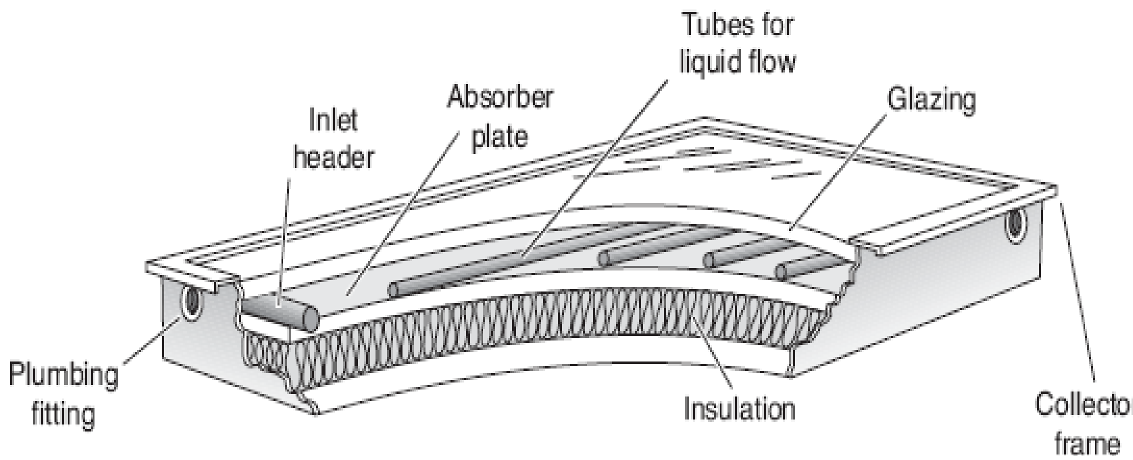

Fig. 9: Glazed flat-plate collector

Figure 10 shows the outline of a flat-plate collector for air heating and the main parameters involved in heat transfers: incident solar radiation (I), cover heat loss coefficient (U_c), coefficient of convective heat transfer between cover and air ($h_{c,c\text{-}a}$), coefficient of convective heat transfer between plate and air ($h_{c,p\text{-}a}$), coefficient of radiation heat transfer between plate and cover (hr,p-c), bottom heat loss coefficient (U_b), ambient temperature (T_{amb}), cover temperature (T_c), air temperature (T_a) and mean plate temperature (T_{pm}). Santos [8] recommended that the latitude must be 22^o53'S, collector tilt must be 23^o and collector area must be 1.8 m^2 for best flat blade collector efficiency.

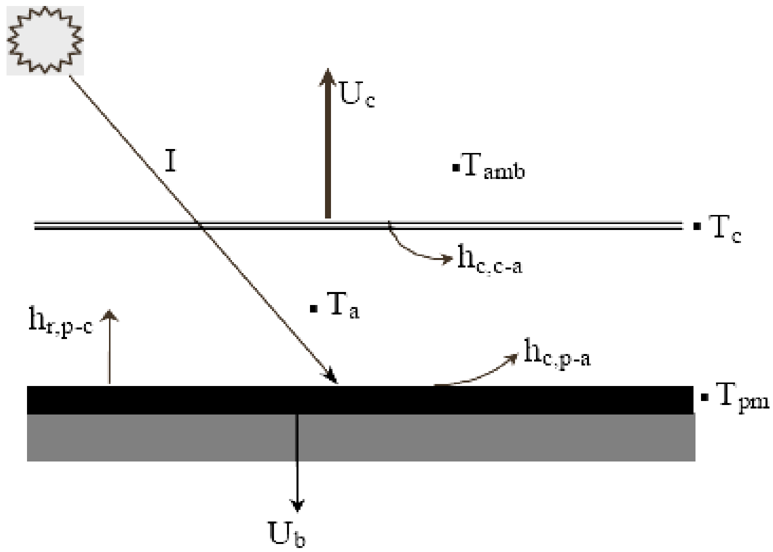

Fig. 10: Flat-plate solar collector heat transfer parameters

A solar collector may be regarded as a conventional heat exchanger transferring heat from solar radiation at a constant temperature T_{max} to the collector fluid. The log mean temperature difference (LMTD) can be written as:

$$LMTD = (T_{out} - T_{in})/\log[(T_{max} - T_{in})/(T_{max} - T_{out})] \quad (21)$$

The back loss might be given by the formula:

$$h_{ba}(T_b - T_a) \quad (22)$$

Where, the heat transfer coefficient is $h_{ba} = 0.3W/m^2K$, T_a = ambient temperature, T_b = black plate temperature, T_c = glass cover temperature, k = thermal conductivity of air = 0.02750W/mK.

In practice it is convenient to use the fluid temperature T_f instead of the black plate temperature T_b. The total heat extraction rate Q_{out} from a collector of area A is written as:

$$Q_{out} = AF' [\gamma.q_{in} – U (T_f - T_a)] \quad (23)$$

Where F' is called the collector efficiency factor (in good designs F' is nearly unity). F'γ is the effective transmittance - absorptance product; and F'U is the heat loss coefficient between the fluid and its surroundings.

The thermal resistance R between the black plate and the fluid can be defined by the equation $q_{out} = (T_b - T_f) /R$, and derive Equ.(21) from the heat balance equation between the black plate and the surroundings. It is then found that: $F' = 1/(1 + RU)$.

Consider a fluid with mass flow rate (m) and specific heat capacity (c) flowing a total distance (L) through a collector of area (A). The heating of the fluid with respect to distance (x) through the collector is given by

$$mc(dT(x)/dx) = (A.F'/L)[\gamma.q_{in} - U(T(x) - T_a)] \quad (24)$$

Assume U is constant. Then this is a first order non-homogeneous linear differential equation. It can be solved to give the basic equation relating the inlet and outlet fluid temperatures T_{in} and T_{out} as follows:

$$[\gamma.q_{in} - U(T_{in} - T_a)]\exp(-AF'U/mc) = [\gamma.q_{in} - U(T_{out} - T_{in})] \quad (25)$$

Often the performance of a collector is written in terms of the fluid inlet temperature T_{in} and a heat removal factor F_R, as follows:

$$Q_{out} = AF_R[\gamma.q_{in} - U(T_{in} - T_a)] \quad (26)$$

Writing $Q_{out} = mc(T_{out} - T_{in})$, and eliminating T_{out} with the help of Equ.(25), shows that:

$$F_R = (mc/AU)[1 - \exp(-AF'U/mc)] \quad (27)$$

For small flow F_R is small and the fluid temperature approaches the stagnation temperature T_{max}. For large flow F_R is large, but the rise in fluid temperature is small.

1.1.2.3 Solar collectors with concentration

Concentration solar collector use special systems in order to increase the intensity of radiation on the absorbing surface and thus achieve high temperatures in the heat carrier fluid. The main complication is the need for a monitoring system to ensure that the collector is permanently oriented towards the sun. Its receiving area is conical or spherical with a cover glass in the same geometry. Figure 13 shows a parabolic trough solar collector (horizontal type), while figure 14 shows a vertical type parabolic trough solar collector. The development of a new generation of large-scale, low-cost solar thermal power plants is the focus of a joint research agreement signed between Algeria and Germany [2]. Researchers will be sharing data and expertise to speed up the market introduction of large-scale solar thermal plants.

The plants could supply up to 200 MW of electricity and desalinate water for 50,000 people.

Another type used in Algeria now is shown in Figure 11. The collectors with concentration are divided into two categories: cylindrical Switch or so called parabolic trough. This type of collector has surface reflector of a half cylinder. Its main application is the production of steam at thermal power stations. The other type is the switch paraboloids or so called parabolic dish: Its surface reflector has the geometry of a paraboloid. Its main application is the production of steam at a thermal power station. Figures 12 - 17 show parabolic dishes solar collectors. Figure 18 shows design of the parabolic concentrator.

Fig. 11: Parabolic trough solar collector

Fig. 12: Parabolic trough solar collectors

Fig. 13: Parabolic trough used in Algeria

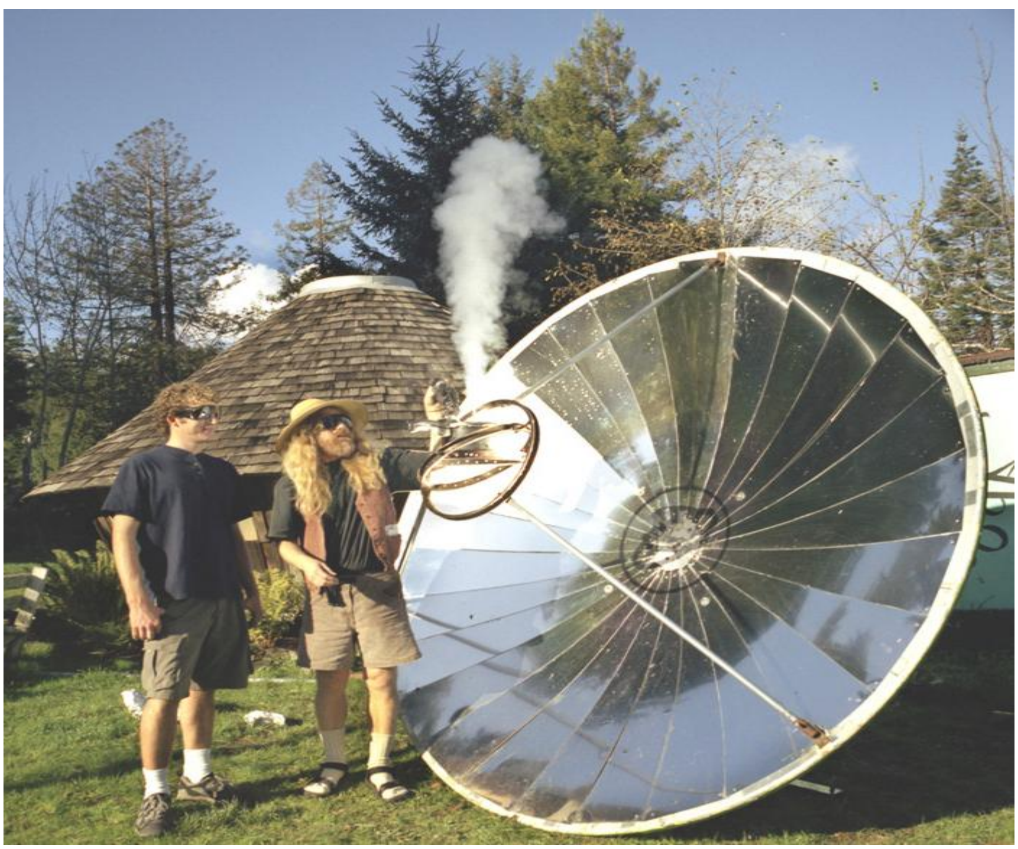

Fig. 14: Parabolic dish solar collector

Fig. 15: Parabolic dishes solar collectors with their trackings

Fig. 16: Parabolic trough solar collector

Fig. 17: The concentrator Fresnel mirror solar collector

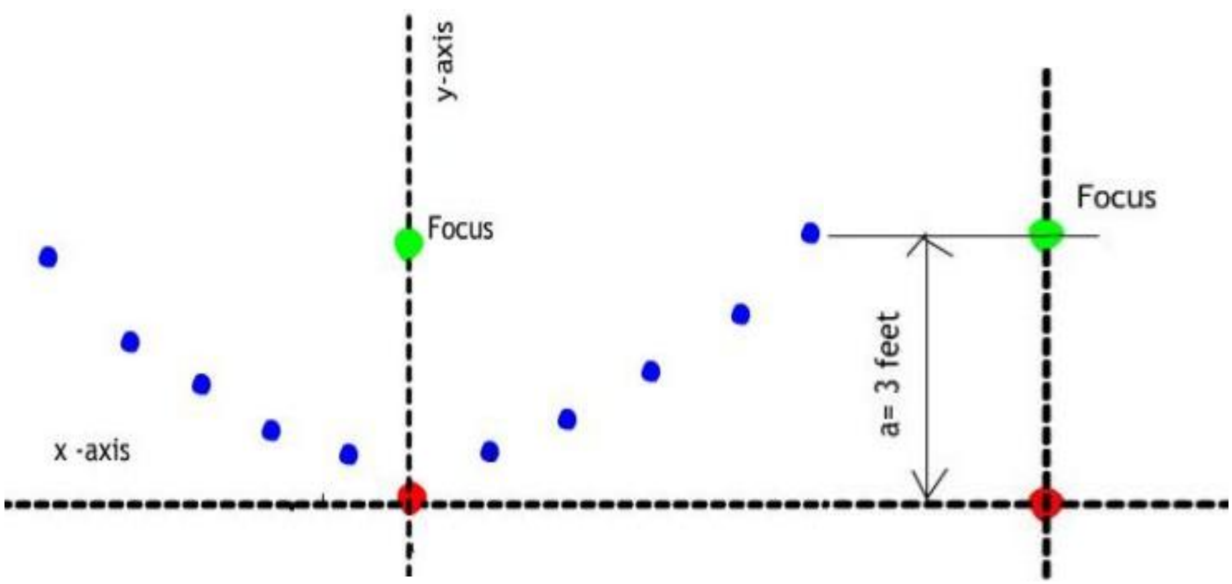

Fig. 18a

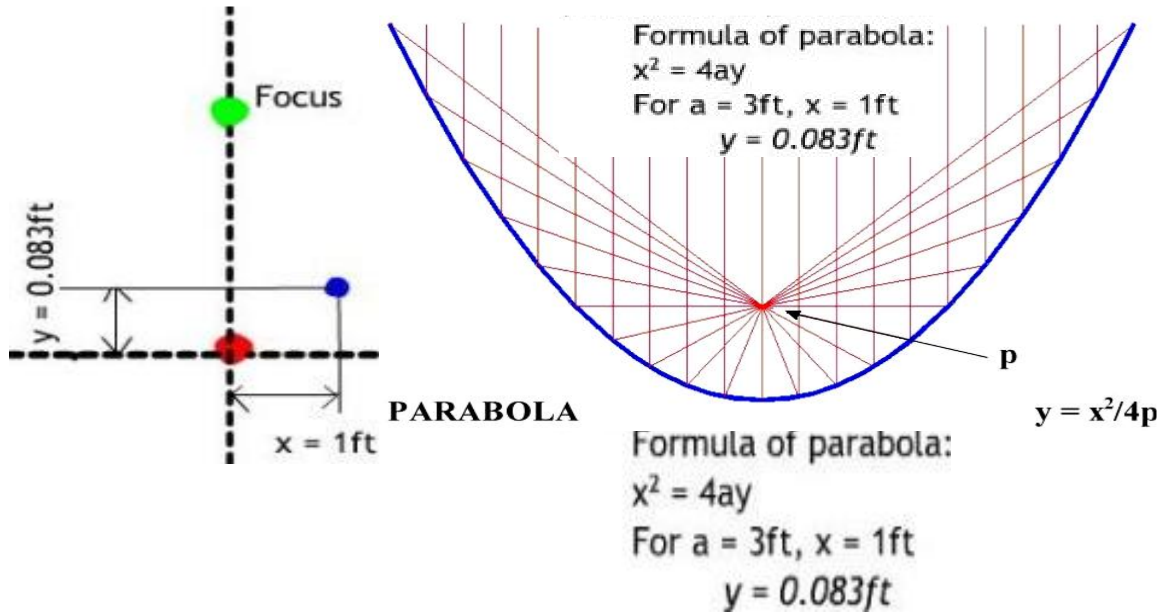

Fig. 18b

Fig. 18: Design of parabolic concentrator

1.1.2.3.1 Application of solar collectors in cooking

Solar cookers use sunlight for cooking, drying and pasteurization [9]. They can be grouped into three broad categories: box cookers, panel cookers and reflector cookers. A basic box cooker consists of an insulated container with a transparent lid. It can be used effectively with partially overcast skies and will typically reach temperatures of 90-150 °C. Panel cookers use a reflective panel to direct sunlight onto an insulated container and reach temperatures comparable to box cookers. Reflector cookers use various concentrating geometries (dish, trough, Fresnel mirrors) to focus light on a cooking container.

The solar bowl is a concentrating technology employed by the solar kitchen in Auroville, India, where a stationary spherical reflector focuses light along a line perpendicular to the sphere's interior surface, and a computer control system moves the receiver to intersect this line. Steam is produced in the receiver at temperatures reaching 150°C and then used for process heat in the kitchen. Figure 19 shows other type of solar cooker type.

A reflector developed by Wolfgang Scheffler in 1986 is used in many solar kitchens. Scheffler reflectors are flexible parabolic dishes that combine aspects of trough and power tower concentrators. Polar tracking is used to follow the Sun's daily course and the curvature of the reflector is adjusted for seasonal variations in the incident angle of sunlight. These reflectors can reach temperatures of 110 - 175 °C and have a fixed focal point, which simplifies cooking. The world's largest Scheffler reflector system in Abu Road, Rajasthan, India is capable of cooking up to 35,000 meals a day. As of 2008, over 2,000 large Scheffler cookers had been built worldwide. Solar cooking on a large scale with parabolic concentrators of 9.2 m^2 is shown in figure 20 which capable of cooking 20 to 40 thousand meals a day.

Fig. 19: The Solar cooker

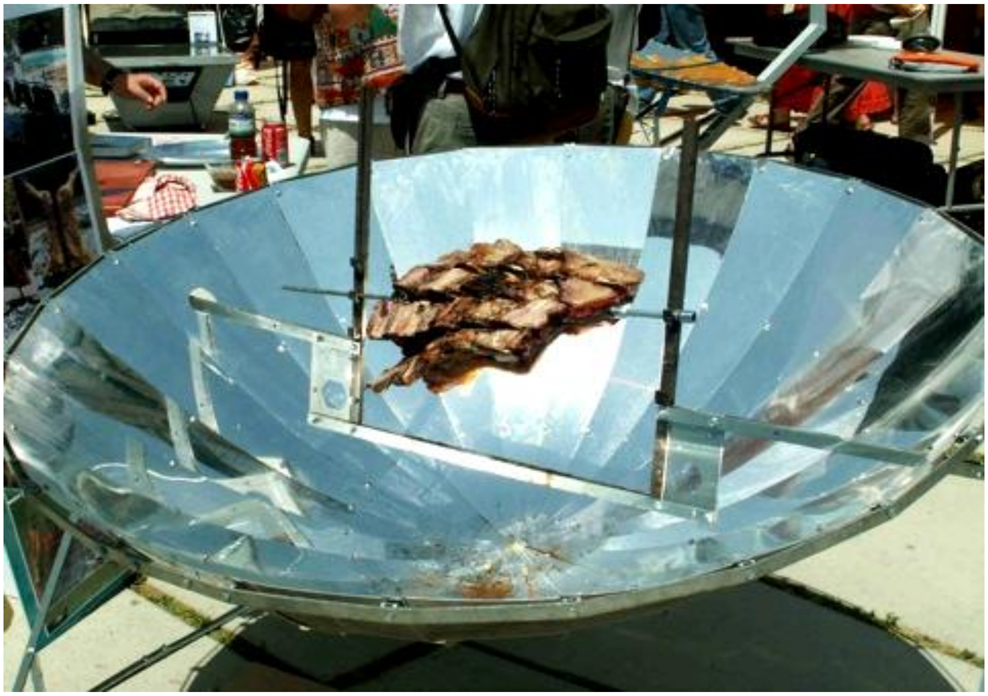

Fig. 20: Solar cooking on a large scale

1.1.2.3.2 Application of solar collectors in electric power generation

In many places around the world they have sunshine and dirty water, and desperately need clean water [10]. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with selective coatings which absorb and retain heat better than ordinary black paint. Absorbers plates are usually made of metal-typically copper or aluminum-because the metal is a good heat conductor. Figure 21 shows the photographs of an arrangement of parabolic solar collectors while the suns energy is focused on the water pipe at its centre.

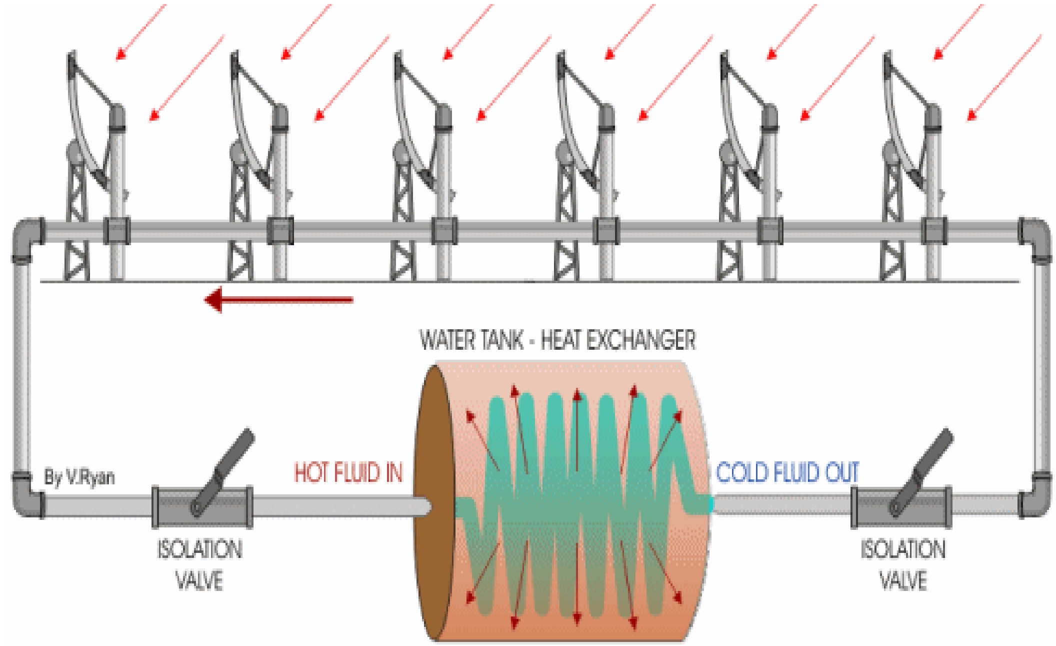

Fig. 21: Photographs of an arrangement of parabolic solar collectors

Figure 22 shows pparabolic trough solar collector for power plant. This figure shows a photograph for two concentrators to explain the concept of three to five concentrators that is used in field depending on site conditions. In the inset the focus on the receiver is shown. Salient features of the new system are:

1. Multiple reflectors with square shape in plan.
2. Compact design as the shape is switched over to square than round.
3. Single axis fixed speed daily automatic tracking eliminates need of sensors.
4. Photograph shows two reflectors of 6.25 m^2 each delivering 2000 to 2500 Watts per reflector. Trials on higher sizes of 10 m^2 and 15 m^2 square and rectangular dishes are to be conducted before standardization.

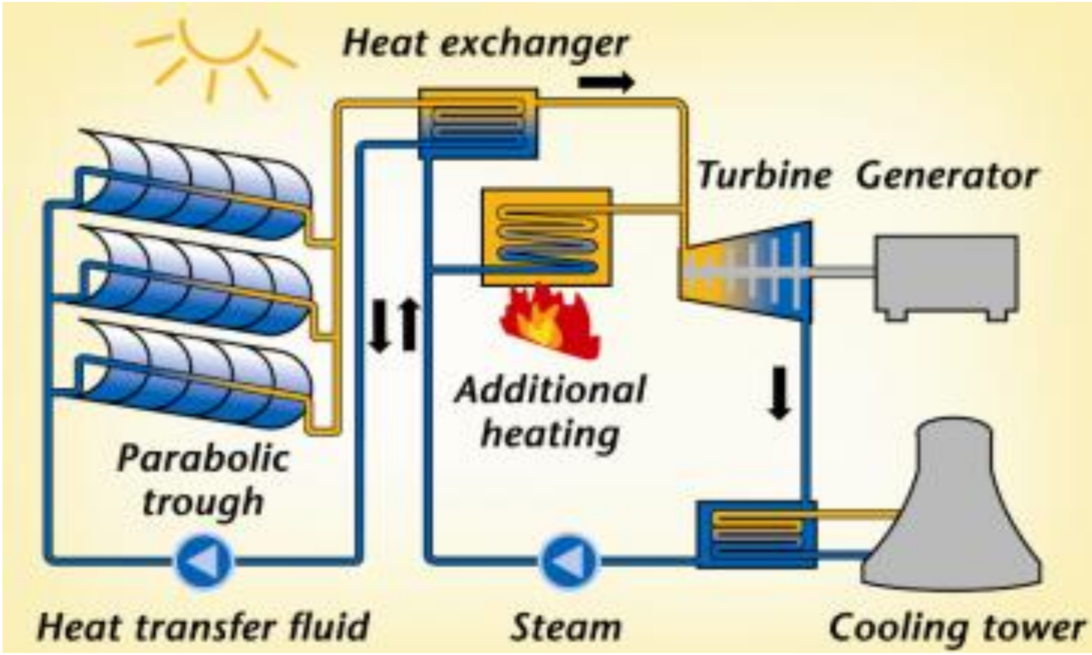

Fig. 22: Parabolic trough solar collector for power plant

1.1.2.3.3 Application of Solar Collector in Desalination of Saline Water

Desalination of saline water has been practiced regularly for over 50 years and is well established means of water supply in many countries. Challenges, however, exist to produce desalinated water at an affordable cost. Most of desalination units operate under expensive fuels like electricity, coal, oil, natural gas etc. To provide potable water at affordable cost, it is imperative to convert fuel operated technology to solar operated technology. Flat-basin is one of the techniques for desalination of water using solar energy. Although flat-basin solar still has advantage of low installation cost, however low efficiency and problem associated with the deposit of salt and scale and corrosion have limited its uses. An average output of 3-4 m^2/day is typical which shows that there is a need to enhance the productivity of this type of desalination system. Production rate of freshwater by using solar distiller with capillary film has also been tested by delivering different temperatures of brine to the solar distiller. The distillate has been found to increase with increasing temperature of incoming brine. The maximum amount of distillate to the tone of 0.75 kg/h-1 m^2

has been attained for 74°C temperature. The performance of metallic cylindrical parabolic reflector for desalination of water was also investigated.

A new solar desalination technique was also investigated [15] where storage tank and two flat plate solar collectors were integrated with a basin type solar still. The collector and the still were coupled to form a naturally circulating closed loop. The average daily production of distilled water was found to be 100% higher as compared to that of a simple basin-type solar still. The effect of using two-axis sun tracking system on the thermal performance of compound parabolic concentrators (CPC) was also investigated. It was reported that tracking CPC collector showed a better performance with an increase in the collected energy of up to 75% compared with an identical fixed collector. The parabolic concentrator was coupled with still in such a way that the solar radiations were made to focus at the base of the tray of the still. The maximum amount of distillate was 2 liter/ h-1 m^2 on August 4, 2002 and minimum amount of distillate 0.370 liter /h-1 m^2.

1.2 Problem Statement Objective

- Take the advantage of the lengthy shoreline of Jazan province on the red sea as a source of seawater to be desalinated.
- Study the efficiency enhancement by using solar energy for the desalination process.
- Understand economic barriers to widespread deployment of renewable energy.
- To study the effect of using solar pond and flat plat collector for preheating the seawater.
- To study the feasibility of the desalination using solar and compare it with conventional desalination plant.
- To study the efficiency and performance enhancement due to the use of parabolic trough instead of parabolic collector, and implementing tracking system.

1-3 Problem justification and Outcomes

1. The project included the engineering fundamental of: thermodynamics, fluid mechanics, heat transfer, and renewable energy.
2. The project includes design and fabricate a solar collectors and desalination system and conduct an experimental test rig.
3. The project includes a design components of solar energy system such as solar pond, flat plate, parabolic dish, evaporation system condenser, piping system, valves, pump and tank.
4. The students have to calculate the heat transfer rate and thermal efficiency of the system
5. Since the solar energy is clean and low cost renewable energy , therefore using the solar energy as energy source is economic and safe the environment.
6. Study of other methods of desalination and made comparison between the different methods to obtain the suitable method of sea water desalination.
7. This project consists of fabrication of solar pond, different solar collectors, condenser and evaporator, piping system that includes of many engineering tools.

1-4 Problem Constraints

All the following design constraints of solar desalination system :

The solar collector size, the amount of product fresh water , the cost of liter fresh water.

CHAPTER 2

DESIGN APPROACH AND METHODOLOGY

2.1 Design approach

The project methodology can be summarized in the following points: Construction of solar pond with approximate dimension of (2 m long × 2 m wide × 1.2 m height). The solar pond will be filled of three layers of salty water with different concentration. Design of heat exchanger to be immersed inside the pond.

2-2 Design Methodology

The whole system is equipped with pump for water circulation and flat plat collector to heat up the solar pond. The system is also equipped with temperature sensors to collect the experiment data. Design and manufacture of a parabolic dish with diameter of 4m. Mathematical models for the system is introduced.

CHAPTER 3

THEORETICAL BACKGROUND

3-1 Design specifications and assumptions

Theoretical analysis is being made to find out the temperature of solution in solar pond and solar still at every instant. Initially both the temperatures are assumed to be equal as ambient.

3-2 Mathematical models and formulations

Theoretical analysis is being made to find out the temperature of solution in solar pond and solar still at every instant. Initially both the temperatures are assumed to be equal as ambient. The temperature of the storage zone, Lower Convective Zone (LCZ) at end of the time interval [20], T_t+d_t is

$$T_{t+\mathrm{d}t} = \frac{\left\{A_s\left[h(z)I_g + k_w T_a / d_{\mathrm{ncz}}\right] + T_t / \mathrm{d}t\right\}}{\left[\left(m_p c_p / \mathrm{d}t\right) + \left(A_s k_w / d_{\mathrm{ncz}}\right)\right]} \tag{1}$$

Initially the temperature of the LCZ is taken as the ambient temperature. The fraction of solar radiation penetrating to the depth z in the pond is taken as 0.7. Figure 23 shows a schematic diagram of the experimental set-up [20]. Specific heat of the saline water, $C_{p,w}$ is calculated from

$$C_{p,w} = a_1 + a_2 T_w + a_3 T_w^2 + a_4 T_w^3 \tag{2}$$

where

$$a_1 = 4206.8 - 6.6197s + 1.2288\times10^{-2}s^2 \tag{2-a}$$

$$a_2 = -1.1262 + 5.4178\times10^{-2}s - 2.2719\times10^{-4}s^2 \tag{2-b}$$

$$a_3 = 1.2026\times10^{-2} - 5.5366\times10^{4}s + 1.8906\times10^{-6}s^2 \tag{2-c}$$

$$a_4 = 6.8774\times10^{-7} + 1.517\times10^{-6}s - 4.4268\times10^{-9}s^2 \tag{2-d}$$

The effectiveness of the copper heat ex-changer is taken [20] as 0.9. The vertical distant (d_{ncz}) of the Non Convective Zone (NCZ) is taken as 12 cm. The saline water is heated while it is passing through LCZ from the Upper Convective Zone (UCZ). For every time interval d_t, the change in saline water temperature is taken as the sum of initial temperature (ambient temperature in the case of first iteration) and the temperature difference obtained from Eq. (1). Like that every time interval the change in temperature is calculated.

The energy balance equation for the absorber plate, saline water and glass of the solar still can be written as follows:

Energy received by the saline water in the still (from sun and base) is equal to the summation of energy lost by convective heat transfer between water and glass, radiative heat transfer between water and glass, evaporative heat transfer between water and glass and energy gained by the saline water.

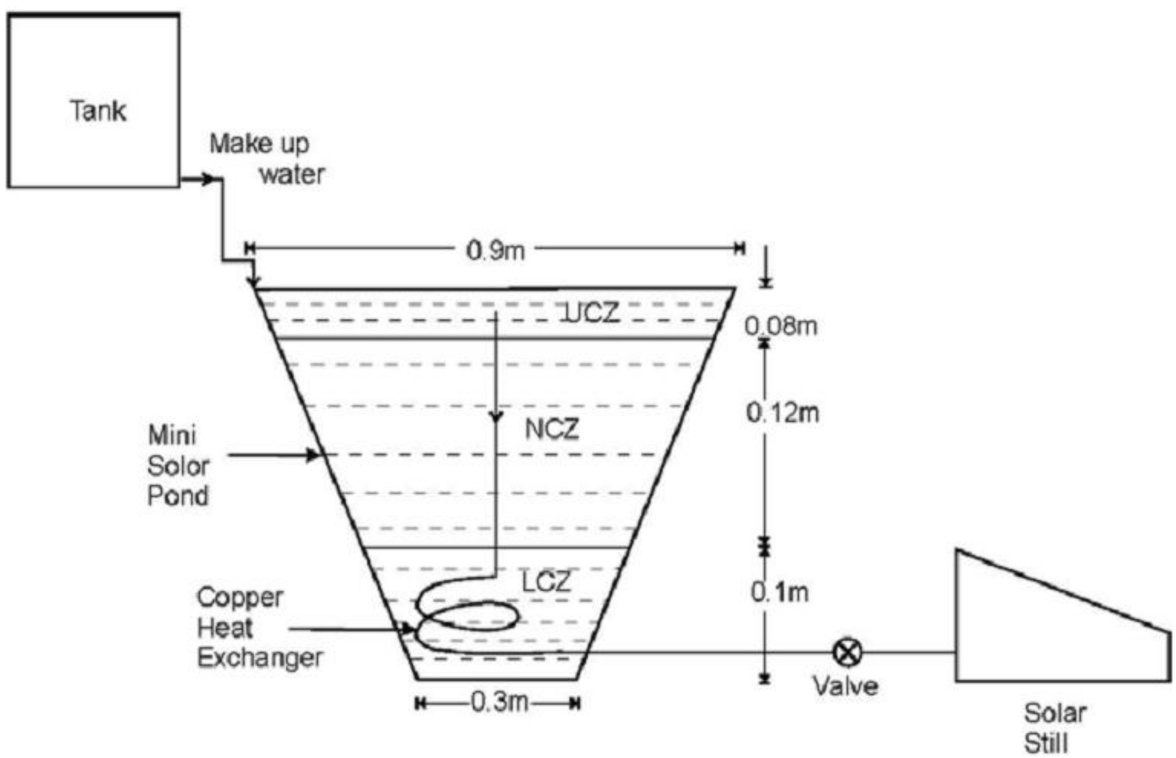

Fig. 23: Schematic diagram of the experimental set-up [20]

$$I(t)\alpha_w + q_{c,\,b\text{-}w} = q_{r,w\text{-}g} + q_{c,w\text{-}g} + q_{e,w\text{-}g} + q_{\text{loss}} + m_w c_{p,w}\,(\mathrm{d}T_w/\mathrm{d}t) \tag{3}$$

The mass of water in the still is maintained as 20 kg. I(t), the total solar flux on an inclined surface is obtained from

$$I(t)=(I_g - I_d)\ (\cos\theta_i/\cos\theta_h) + I_d(1+\cos\beta)/2 \tag{4}$$

where θ_i and θ_h are the incidence angles on an inclined surface and horizontal surface respectively and are obtained from

$$\theta_i = \cos^{-1}\,[\cos(\varphi-\beta)\cos\delta\cos\omega + \sin(\varphi-\beta)\sin\delta] \tag{4-a}$$

and

$$\theta_h = \cos^{-1}\,[\cos\varphi\,\cos\delta\,\cos\omega + \sin\varphi\,\sin\delta] \tag{4-b}$$

The absorptivity of the still α_w is taken [20] as 0.05.

The convective heat transfer between basin and water is given by [20]

$$q_{c,\,b\text{-}w} = h_{c,\,b\text{-}w} A_b (T_b - T_w) \tag{5}$$

The convective heat transfer coefficient between basin and water is taken as 135 W/m^{2}K.

The convective heat transfer between water and glass is given by

$$q_{c,w\text{-}g} = h_{c,w\text{-}g}\,(T_w - T_g) \tag{6}$$

The convective heat transfer co-efficient between water and glass is given by

$$h_{c,w-g} = 0.884\left[\left(T_w - T_g\right) + \frac{\left(P_w - P_g\right)\left(T_w = 273.15\right)}{\left(268.9\times10^3 - P_w\right)}\right]^{1/3} \tag{7}$$

The radiative heat transfer between water and glass is given by

$$q_{r,w\text{-}g} = h_{r,w\text{-}g}\,(T_w - T_g) \tag{8}$$

The radiative heat transfer co-efficient between water and glass is given by

$$h_{r,w\text{-}g} = \varepsilon_{\text{eff}}\,\sigma\,(T_w^2 + T_g^2)\,(T_w + T_g) \tag{9}$$

where,

$$\varepsilon_{\text{eff}} = (1/\varepsilon_w + 1/\varepsilon_g - 1)^{-1} \tag{10}$$

The evaporative heat transfer between water and glass is given by

$$q_{e,w\text{-}g} = h_{e,w\text{-}g}\,(T_w - T_g) \tag{11}$$

The evaporative heat transfer co-efficient between water and glass is given by

$$h_{e,\,w\text{-}g} = (16.273\times10^{-3})\; h_{c,w\text{-}g}\,(p_w - p_g)/(T_w - T_g) \tag{12}$$

Side losses are calculated from

$$q_{\text{loss}} = U_b A_b\,(T_b - T_a) \tag{13}$$

where U_b is taken [2] as 14 W/m^{2}K.

Energy gained by the glass cover (from sun and convective, radiative and evaporative heat transfer from water to glass) is equal to the summation of energy lost by radiative heat transfer between glass and sky and energy gained by glass.

$$I(t)\,\alpha_g + q_{r,w\text{-}g} + q_{c,w\text{-}g} + q_{e,w\text{-}g} = q_{r,g\text{-}sky} + m_g c_{p,g}\,(\mathrm{d}T_g/\mathrm{d}t) \tag{14}$$

The radiative heat transfer between glass and sky is given by

$$q_{r,g\text{-}sky} = h_{r,g\text{-}sky}\,(T_g - T_{sky}) \tag{15}$$

The radiative heat transfer co-efficient between glass and sky is given by

$$h_{r,g\text{-}sky} = \varepsilon\text{eff}\;\sigma\,(T_g^2 + T_{sky}^2)\,(T_g + T_{sky}) \tag{16}$$

where

$$\varepsilon_{\text{eff}} = [1/\varepsilon_g + 1/\varepsilon_g - 1]^{-1} \tag{17}$$

In the above equation, the right hand side, first and second terms indicate emissivities of the inner and outer surfaces of the glass, and effective sky temperature T_{sky} is given by

$$T_{sky} = T_a - 6 \tag{18}$$

The glass temperature and increase in saline water temperature are computed by solving Eqs.14 and 3 respectively. For evaluating the change in saline water temperature in the simulation, the experimentally measured values of solar radiation and ambient temperature of the corresponding day and hour were used. The total condensation rate is given by

$$\mathbf{Q = m * cp * Dt = hfg*dm/dt} \qquad (19)$$

h_{fg} is calculated for saline water temperature T_w. For the next time step, the parameter is redefined as:

Sensible energy gained by the solution in the still = sensible energy rise in the still during direct heating + sensible energy of solution coming from the solar pond (20)

The solution temperature obtained from Eq.1 is used to find out the sensible energy of solution coming from solar pond and the solution temperature predicted in Eq.3 is used to determine the sensible energy rise in the still during direct heating and temperature of the solution (T_w) obtained from Eq.20 is taken for the next iteration.

In general, when a body of fluid is heated, its density decreases as its temperature increases. Before describing a solar pond, It must be review briefly what happens in an ordinary pond, e.g. a garden pond. Part of the sunlight incident on the pond is absorbed on the bottom of the pond. The latter absorption leads to heating of the water in the lower part of the pond. The warmer fluid, becoming lighter, rises to the surface, where it losses some of its heat due to the difference between the warm surface temperature and the ambient and through evaporation from the surface. As the surface fluid cools, it gets heavier and sinks to the bottom again. This way, convection currents occur in the fluid due to the buoyancy effects. Because of this continuous mixing and, thus, the loss of heat, it is impossible to capture and store heat in a covered pond. A solar pond is designed to suppress this convection and retain the heat at the bottom of the pond. Several techniques have been proposed to suppress this convection effect. Among these, the salt gradient solar pond is the most studied and most common type [18-20]. Figure 24 shows the concentration and temperature profiles of a salt gradient solar pond.

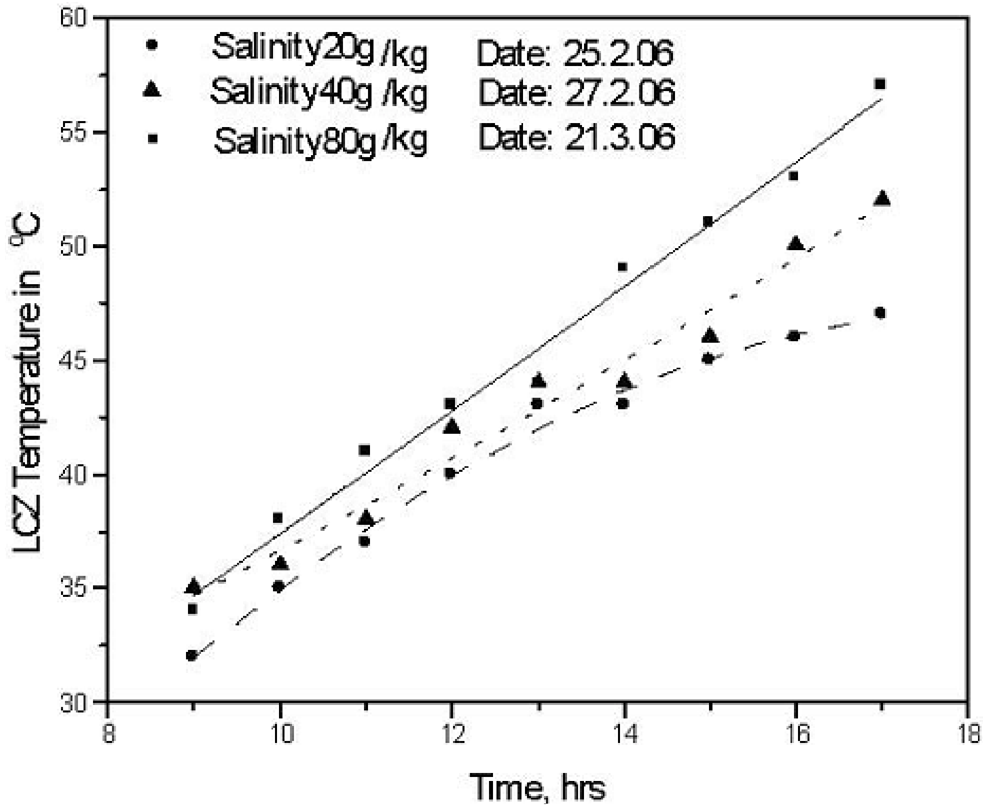

Fig. 24: Effect of varying salinity in the pond on LCZ temperature.

CHAPTER 4

DESIGN PROCEDURE AND IMPLEMENTATION

4.1 Design Procedures

In the present project different solar collectors are used in order to convert solar energy to thermal energy. Three types of solar energy collectors were designed and manufactured in the present work. The first type of solar collector is a solar pond with different salinity, the second type is a flat plate solar collector, and third type is a parabolic dish solar collector.

4.1.1 Design and Conduct of the Solar pond

4.1.1.1 Salinity-Gradient the Solar Pond

The present solar pond is a shallow pond with a vertical salt water gradient, so that the denser saltier water stays at the bottom of the pond and does not mix with the upper layer of fresher water. The solar pond collects solar energy by absorbing direct and diffuse sunlight. It consists of three layers of saline water with different salt concentrations. The present salt-gradient solar pond has a high concentration of salt near the bottom (30%), a non-convecting salt gradient middle layer (with salt concentration increasing with depth), and a surface convecting layer with low salt concentration. Sunlight strikes the pond surface and is trapped in the bottom layer because of its high salt concentration. Therefore, the highly saline water, heated by the solar energy absorbed in the pond floor, cannot rise owing to its great density. It simply sits at the pond bottom heating up until it almost boils (while the surface layers of water stay relatively cool)!. The bottom layer in the solar pond that called the storage zone, is very dense and is heated up to 100°C [22]. Figure 25 shows the density profile of the solar pond. This hot brine can then be used as a day or night heat source from which a special organic-fluid turbine can generate electricity. The middle gradient layer in solar pond acts as an insulator, preventing convection and heat loss to the surface. Solar ponds are particularly well suited to association with desalination plants as waste brine from desalination can be used as the salt source for the solar pond density gradient. Using desalination brine for solar ponds not only provides a preferable alternative to environmental disposal, but also a convenient and inexpensive source of solar pond salinity.

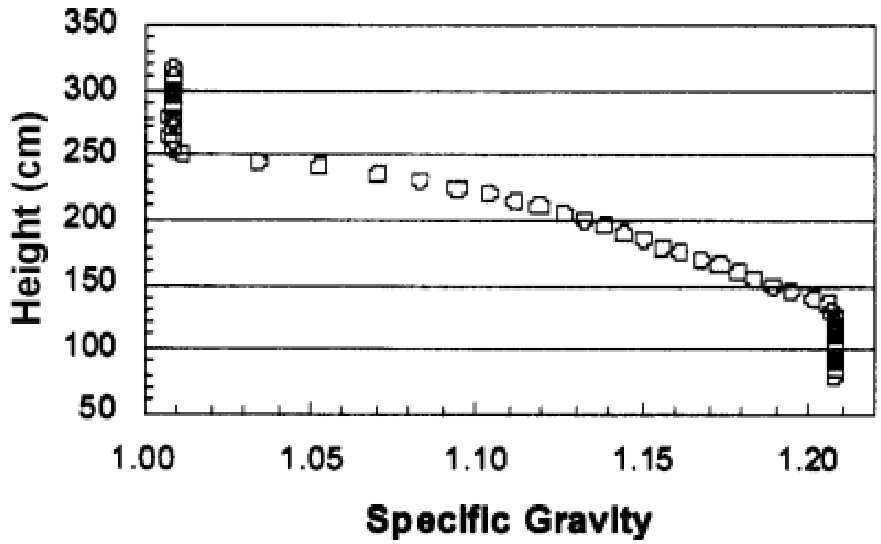

Fig. 25: Density profile of the solar pond [22]

4.1.1.2 Present Solar Pond Design and Description

The present solar pond has a surface area of 4.8 m^2 (2m length, 2m width, and 1.2 m height) as shown in figure 26. A photo for the present solar pond size is shown in figure 27. The lower convective zone (LCZ), the non-convective zone (NCZ) and upper convective zone (UCZ) are approximately 0.3 m, 0.4 m, and 0.5 m, respectively. The pond uses an aqueous solution of predominantly sodium chloride (NaCl). The LCZ contains saturated or near-saturated brine with a concentration of about 30% by weight. The concentration in the UCZ (surface zone) is normally maintained at 2 - 5% salt by weight.

The heat from a solar pond is usually extracted in one of two ways. The first method is to pump the hot brine from the storage zone of the pond to a heat exchanger located near the pond. The second method is to pump a heat exchanger fluid, usually fresh water, through a heat exchanger located within the LCZ of the pond. At the solar pond, hot brine is pumped from the storage zone by means of a diffuser mounted in the storage zone, passed through an external heat exchanger, then returned to the bottom of the pond through another diffuser. The extraction diffuser can be moved to the height of maximum temperature in the storage zone and the return diffuser is placed at the pond bottom. This method insures that the cooler brine is returned to the bottom, reducing ground losses, and that the piping can be easily removed for inspection and repair.

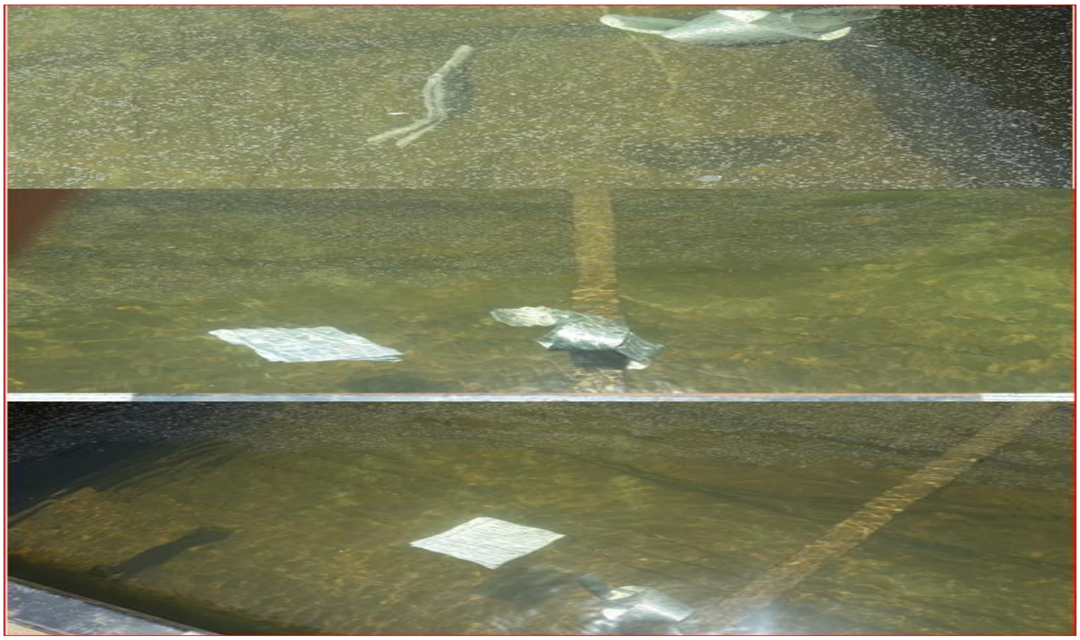

Fig. 26: Photo of the present solar pond salt gradient

Fig. 27: Photo of the present solar pond size

4.1.1.3 Solar Pond Performance

The typical temperature profile of the solar pond is shown Figure 28 [22]. The operation temperature of the pond ranged from 70°C in winter to 90°C in early fall. The highest temperature observed at the solar pond during these years was 93°C, and the maximum temperature difference between the LCZ and UCZ was well above 70°C. The observed temperatures in the storage zone at the bottom of the pond were influenced by ambient conditions and periodic heat removal to operate testing equipment and generate electricity. During the summer months heat is specifically removed from the solar pond, usually by generating electricity in order to maintain the stability of the gradient zone and to prevent boiling. They also measured the average ambient temperature and recorded the solar pond average temperature as shown in Figure 29. It can be seen that the pond surface temperature is quite close to the ambient temperature for most of the year, except for the summer months. Figure 30 shows the temperature variation in the LCZ of the solar pond during a day.

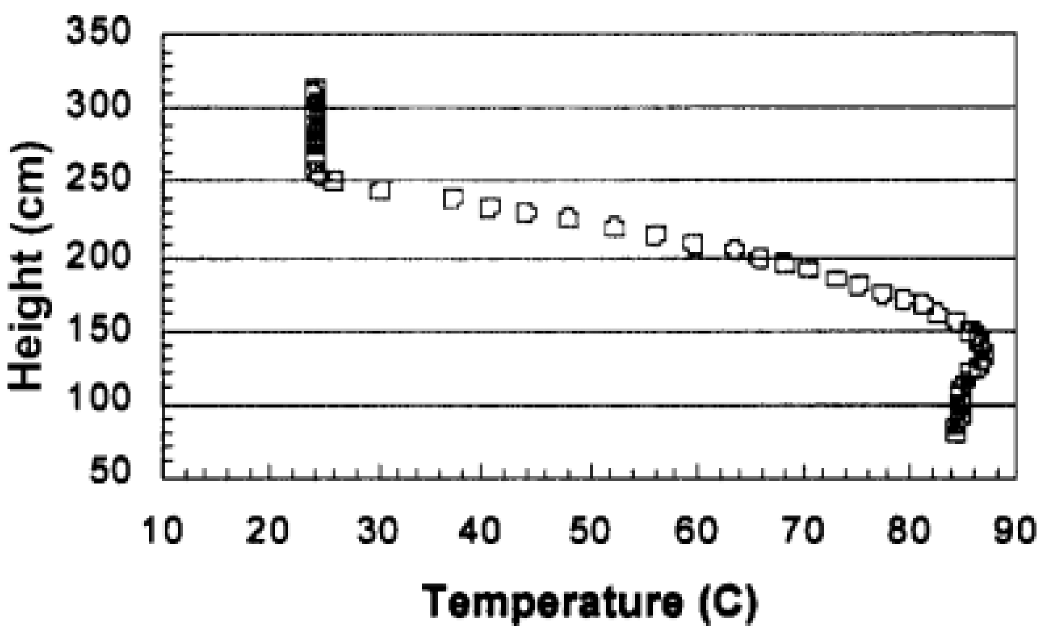

Fig. 28: Temperature profile of the present solar pond [22]

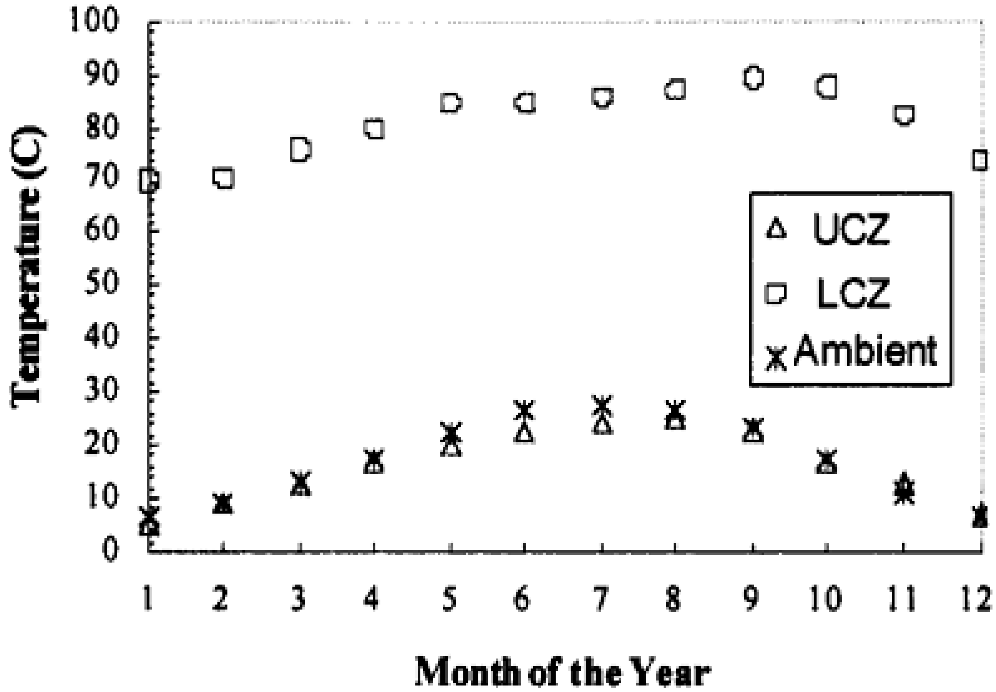

Fig. 29: Temperature development in the solar pond [22].

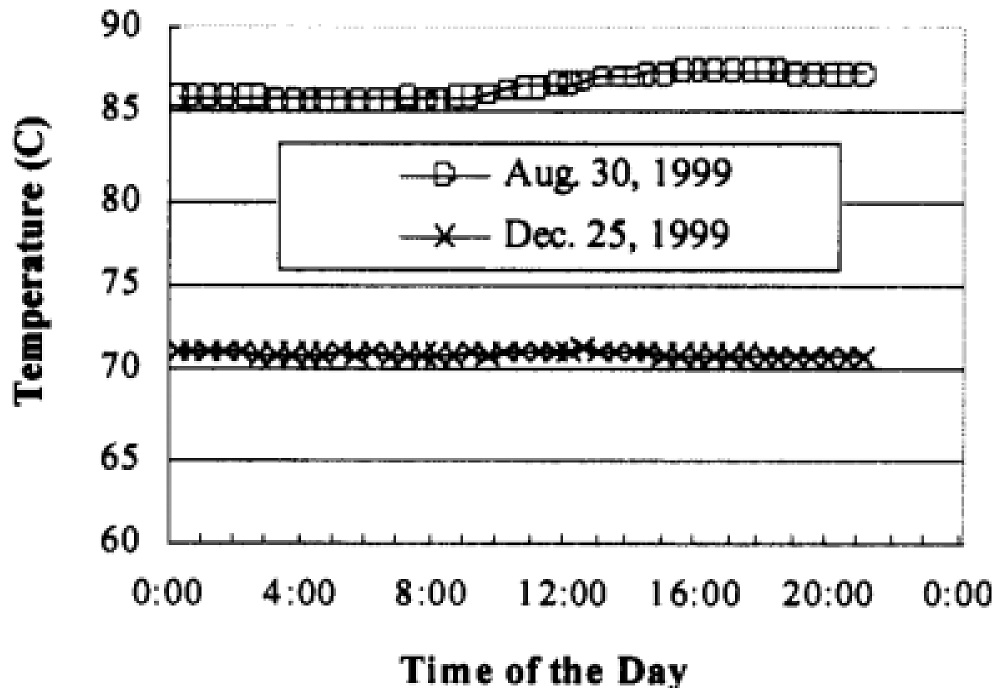

Fig. 30: Temperature variation in the LCZ of the solar pond during a day [22].

The surface temperature is several degrees lower than the ambient temperature. For this reason, the solar pond surface can be used as a cooling source for the thermal desalting processes. The temperature of the LCZ varies seasonally, as shown in Figure 27. However, its variation between day and night is about 1–3°C due to the thermal storage capacity in the pond. This is a very important factor for providing a steady heat supply to the thermal desalination processes. During a typical day in the summer, the storage zone temperature starts to increase at about 8AM and stops increasing at about 8PM. The temperature variation in the LCZ of the solar pond during a day is sown in figure 28. The bottom temperature can increase up to 3°C a day during the spring heating season if no heat is extracted. More generally, the rate of heating of the storage zone is proportional to the incoming solar radiation and inversely proportional to the thickness of the storage zone. The thickness of the storage zone can be increased to increase the storage capacity or decreased to increase the temperature response.

4.1.1.4 Flat-plate collector

The flat-plate collectors (FPCs) are used as heat transfer fluid, which circulates through absorber pipes made of either metal or plastic. The absorber pipes are assembled on a flat plate and they usually have a transparent protective surface in order to minimize heat losses. They may have different selective coatings to reduce heat losses and to increase radiation absorption.

Usually, the flat-plate collector is constructed from an insulated metal box with a glass or plastic cover and a dark colored absorber plate. The flow tubes can be routed in parallel or in a serpentine pattern. The flat plate collectors have not been found as a useful technology for desalination. Although they have been used for relatively small desalinated water production volumes, production of large volumes of water would require an additional energy source, for example, a desalination facility derives energy from flat plate collectors and parabolic troughs.

4.1.2 Design and construction of a flat plate collector

Figure 31 shows a flat plate collector elements. Figure 32 shows the present flat plate collector (in dimension of 2m length and 1 m width) which constructed from an insulated metal box a black colored absorber plate a frame, a cooper tube absorber, and a glass sheet in the upper face.

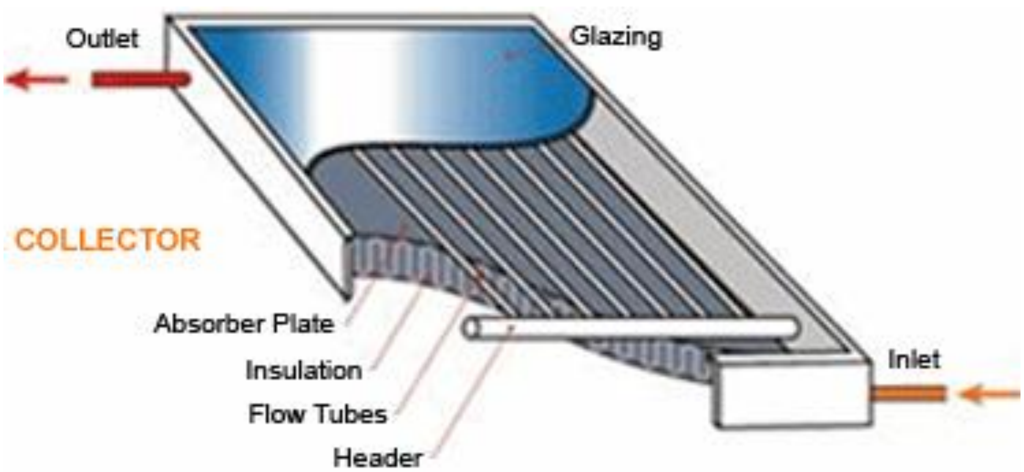

Fig: 31: A flat plate collector elements

Fig. 32: Present flat plate solar collector

4.1.3 Design consideration of a parabolic dish

Using the parabolic dish which is called concentrating solar collector, heat from the sun is concentrated on a black absorber located at the focus point of the reflector in which water is heated to a very high temperature to form steam [23-26]. The present solar parabolic dish is made from steel sheets and lined with glass mirrors. The reflector plain mirror cut into shapes and fixed by glue to the steel sheet as a reflecting surface of the parabolic dish that converges heat to the base of the absorber. However, the basic principle adopted in the construction of the parabolic dish is that when parallel rays of light from the sun close to and parallel to the principal axis are incident on a concave or parabolic shaped mirror, they converge or come together after reflection to a point F on the principal axis called the principal focus as shown in Figure 33.

The parabolic dish solar collector which is used in the present project is made from steel sheet of approximately 200 mm diameter and contains the following parts: parabolic dish reflector, adjustable mechanism, absorber and necessary valves and pipes. The absorber is a metal container that carries water, painted black and located at the focal point of the parabolic dish as shown in figure 34. The construction of the parabolic dish solar steam generator was made taking into account following design specifications:

1. Diameter of the sun: 1.39×10^6 km,
2. Average distance of the sun from the earth: 1.5×10^8 km,
3. Radius of the earth (r_e): 6400 km,
4. Effective temperature of the surface of the sun 5762 K,
5. Solar radiation incidence in Jazan, I = 1260 Watts/m^2,

When the sunlight rays are incident on the reflective surfaces of the parabolic dish, they are reflected and converged to the base of the absorber located at the focal point to heat up the water in it and generate steam. The flexible pipe is a pipe made of galvanized steel. The area of the reflector is obtained from all the quantity of heat to boil water to steam in relation to the design insulation. Heat required for boiling of 1kg of water Q

$$Q = m * Cp * dT \quad = 1.0 \times 4.18 \times (315 - 85) = 961.4 \text{ kJ}$$

Fig. 33: Parabolic dish solar collector

Fig. 34: Receiver of the parabolic dish solar collector

4.2 Design Implementation

A sketch for present test rig for solar collectors and desalinated water or the experimental test facility is shown in Figure 35. It mainly consists of four parts namely, solar pond, solar flat plate collector, parabolic dish and evaporation condenser unit (distilled system). The solar flat plate collector has an area of 2 m^2. The cross sectional area of the pond is 4 m^2. The height of the pond is 1.2 m. This solar pond is connected in parallel with the flat plate collector. The outlet heated water from the solar pond or from the flat plate collector is connected to the parabolic dish solar collector of an area of 2m^2 and the steam outlet from the parabolic dish is connected to evaporation system.

Three zones are being maintained in the present solar pond. They are the upper convective zone (UCZ) with depth of 30 Cm, non-convective or medium zone (NCZ) with depth of 60 Cm and lower convective zone (LCZ) of a depth of 30 Cm. The evaporation condenser unit consists of inner container inside larger one. The inner container is of 70 Cm length, 30 Cm width and 15 cm high, while the larger box is 100 Cm length, 50 cm width and maximum high of 50cm. The larger box is covered by 5 mm glass which inclined by 30 degree as shown in Figure 36 . The hot water coming from solar collectors is flashed in the inner container. The vapor is condensate on the glass and fresh water gathered in the large box.

The necessary elements are added to the present experimental test facility, i.e. a circulating pump with maximum mass flow rate of 0.25 kg/s driven by a 1 hp A.C. motor, a several valves. The pump circulates water from the feeding tank through the absorber tube of the solar collectors back to the collecting tank. The water temperatures at the outlet of the each absorber tube and water mean flow rate are continuously measured during the experiment.

A parabolic dish solar collector adjustable mechanism is made of metal to support the weight of parabolic dish and absorber. The main function is to allow the parabolic dish to align at various angles to capture the sunlight rays depending on the movement and position of the sun. A photo for present test rig for solar collectors and desalinated water or the experimental test facility is shown in Figure 36.

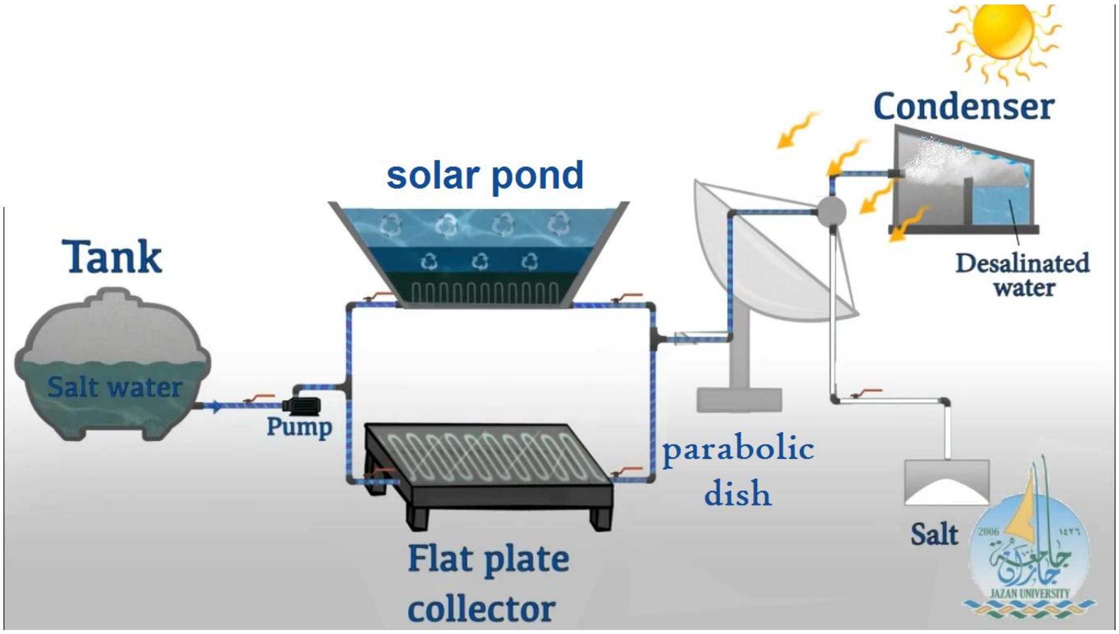

Fig. 35: Sketch for present test rig for solar collectors and desalinated water

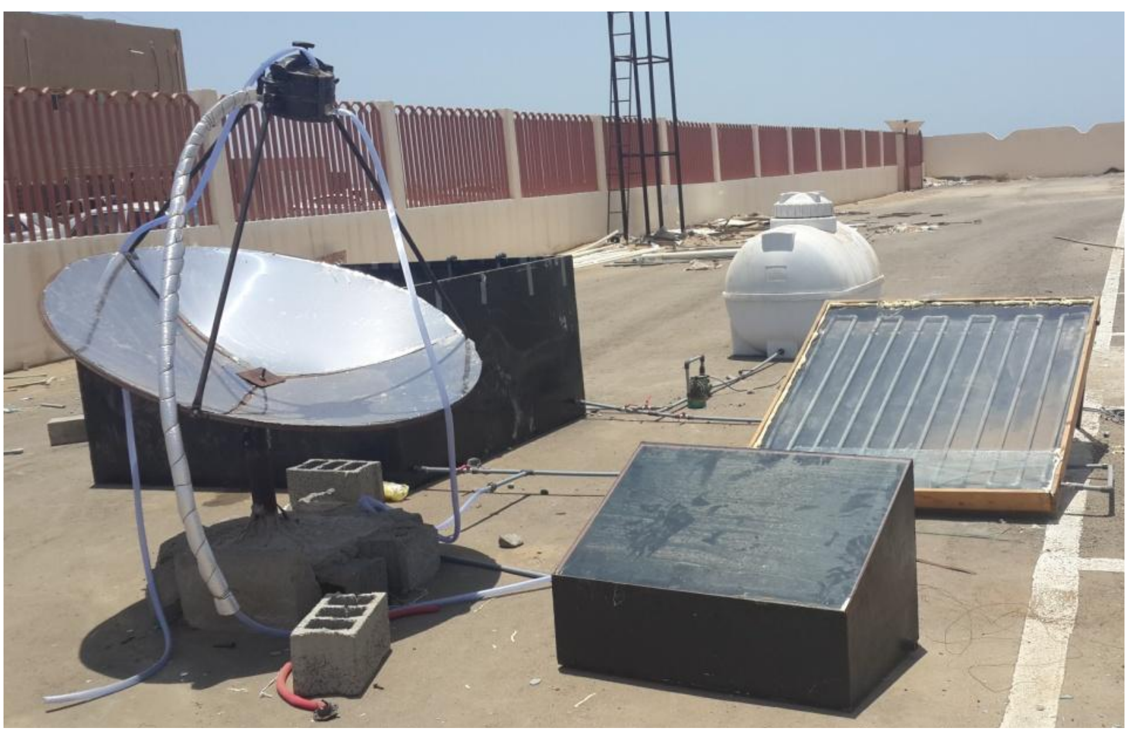

Fig.36: A photo for present complete test rig

The experiments were carried out for the present test rig of the solar pond, flat plate collector and the parabolic dish collector every hour through three days from April 23-25, 2014 for different distilled flow rates. A sample of the results obtained is listed in Table 1 (Appenix-1) for water mass flow rate of 0.1 kg/s on 23nd of April, 2014.

The present solar pond is consists of three layers of saline water with different salt concentrations. The salt-gradient solar pond has a high concentration of salt near the bottom (30%), a non-convecting salt gradient middle layer (with salt concentration increasing with depth), and a surface convecting layer with low salt concentration. Sunlight strikes the pond surface and is trapped in the bottom layer because of its high salt concentration. Therefore, the highly saline water, heated by the solar energy absorbed in the pond floor, cannot rise owing to its great density. It simply sits at the pond bottom heating up until it almost boils (while the surface layers of water stay relatively cool)!. Figure 38 shows the density profile of the solar pond .The bottom layer in the solar pond that called the storage zone, is very dense and is heated up to 87°C as shown in figures 39-41. The middle gradient layer in solar pond acts as an insulator, preventing convection and heat loss to the surface. Solar ponds are particularly well suited to association with desalination plants as waste brine from desalination can be used as the salt source for the solar pond density gradient. Using desalination brine for solar ponds not only provides a preferable alternative to environmental disposal, but also a convenient and inexpensive source of solar pond salinity.

The temperature profile for the present solar pond is shown in figures 39-41 for three regions against the day hours. This figure shows clearly that the solar pond gives a maximum temperature of 87^{o}C through the day, the flat plate collector give about 70^{o}C at 12 AM, while the parabolic dish give very high temperature of 250^{o}C. The highest values of temperature are attained at the highest intensity of solar radiation.

Figure 37-41 show the temperature history of both the UCZ and LCZ of the pond through the April of 2014. The temperature of the lower convective zone increased at an average rate of 1°C per day from April 23 to April 25 of 2014, through three days. After reaching an operating temperature of 87 °C on April 25, the pond began providing heat to the condenser unit, as well as to a thermal desalting unit.

Consequently, the lower salty layer gets very hot (70–87°C). This heat can be used to make electricity (with additional heating from traditional sources), provide energy for desalination, and to supply energy space heating in buildings. To augment the productivity of the potable water in a solar still, several modifications are being carried out in this work. The effect of operational parameters namely salinity in the solar pond and meteorological parameters namely solar radiation on productivity of potable water, glass and water temperature in the still, temperature of various zones in the solar pond and are studied. Figure 42 shows the temperature profile of the solar pond.

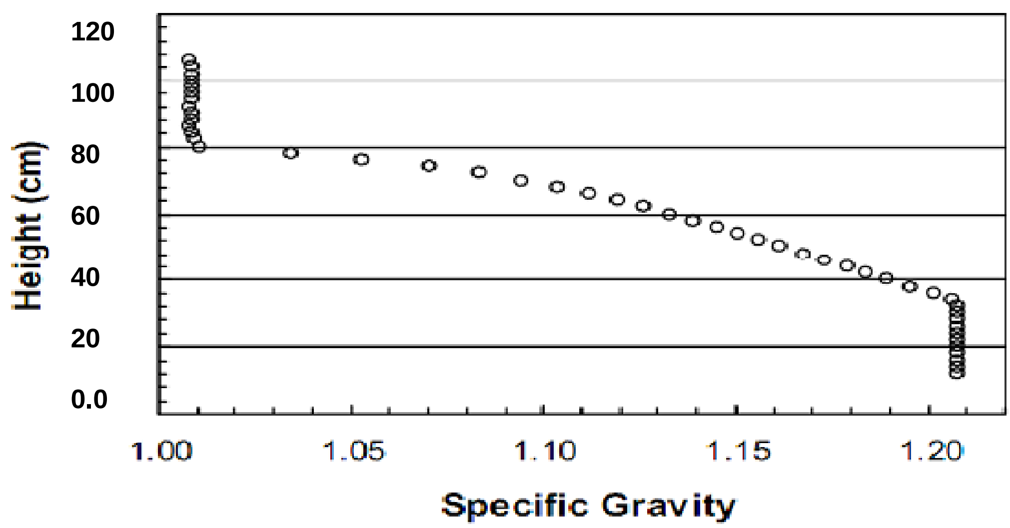

Fig.37: Specific gravity profile of the solar pond

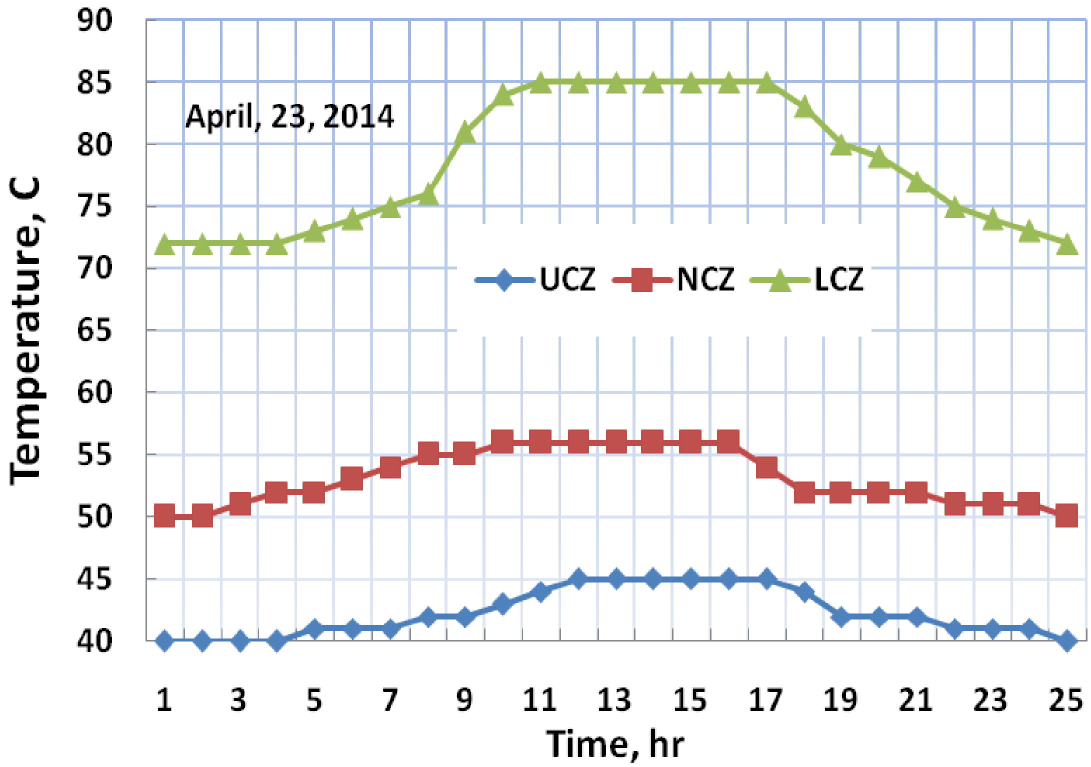

Fig.38: Temperature variation through the day time, April,23, 2014

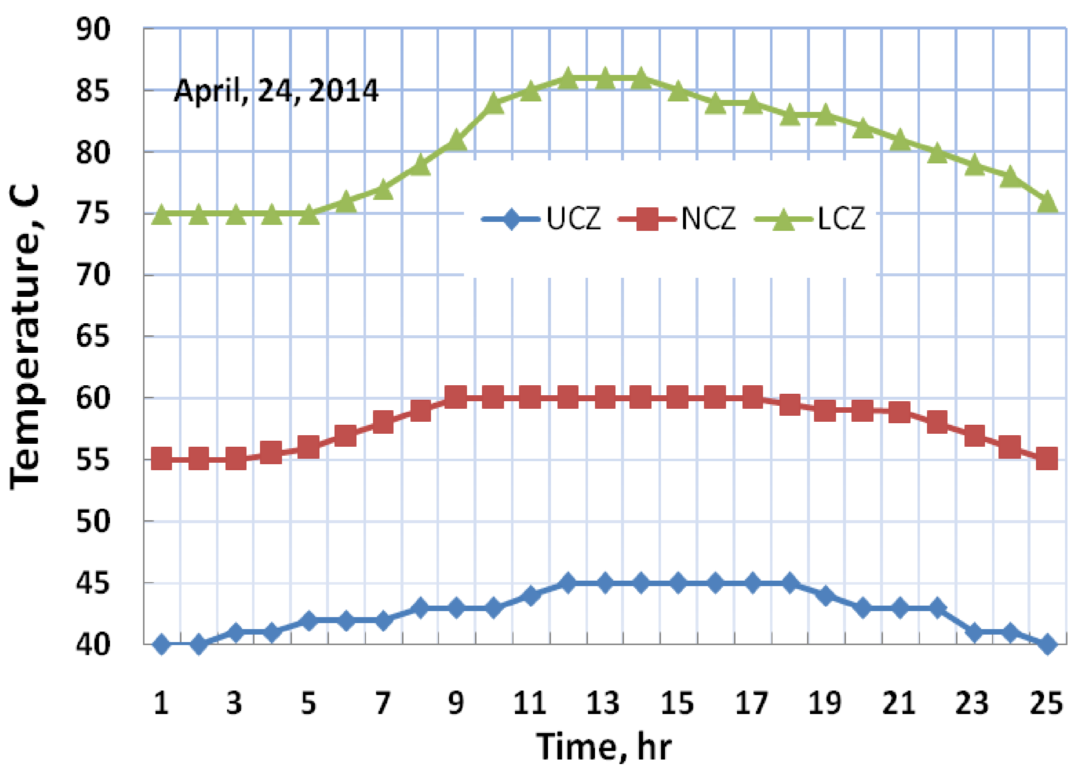

Fig.39: Temperature variation through the day time, April,24, 2014

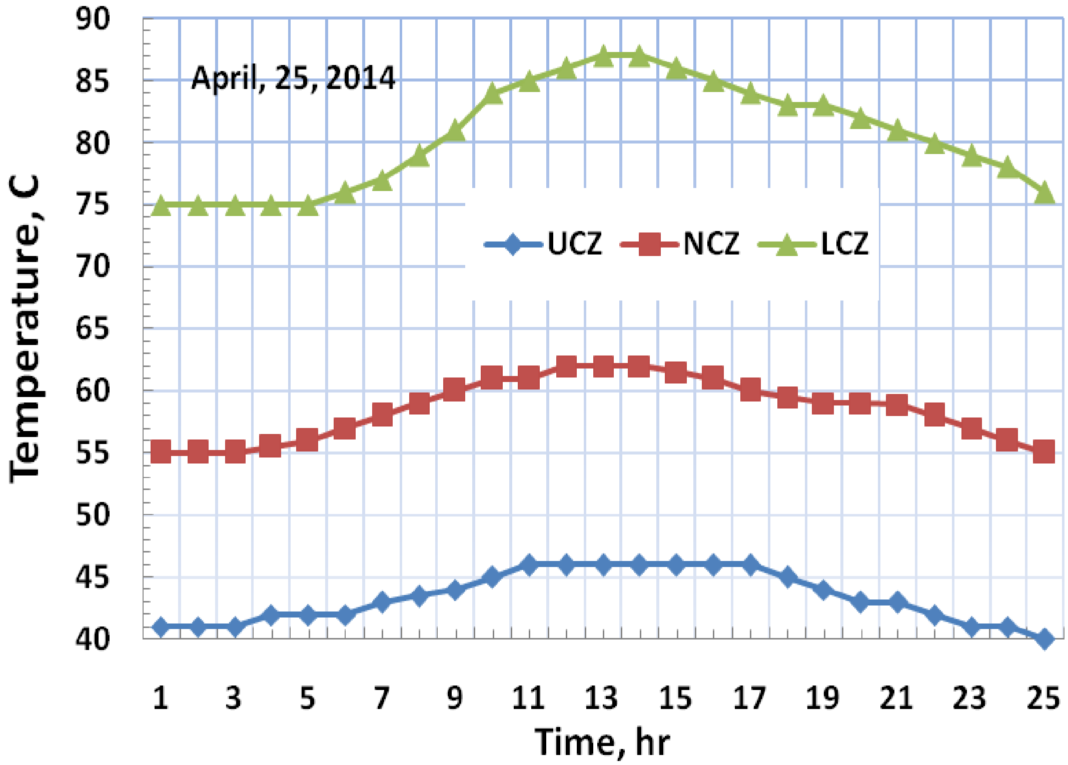

Fig.40: Temperature variation through the day time, April,25, 2014

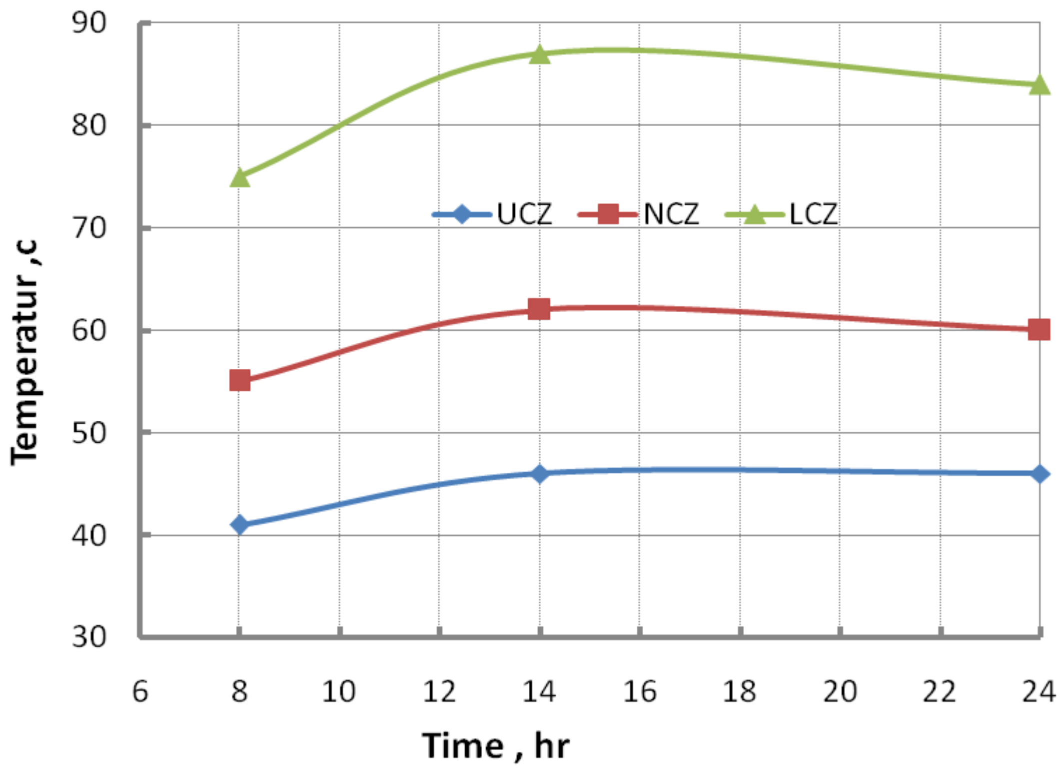

Fig. 41: Temperature profile of the solar pond

Figure 42 shows the temperature variations for the flat plate collector through three days of April 27-29, 2014. This figure shows that the flat plate collector gives the highest temperature at the time of 2 PM and the temperature decreases after and before that time with sharp decreases especially at the day night, while with solar pond the temperature decreases not so sharp at the day night.

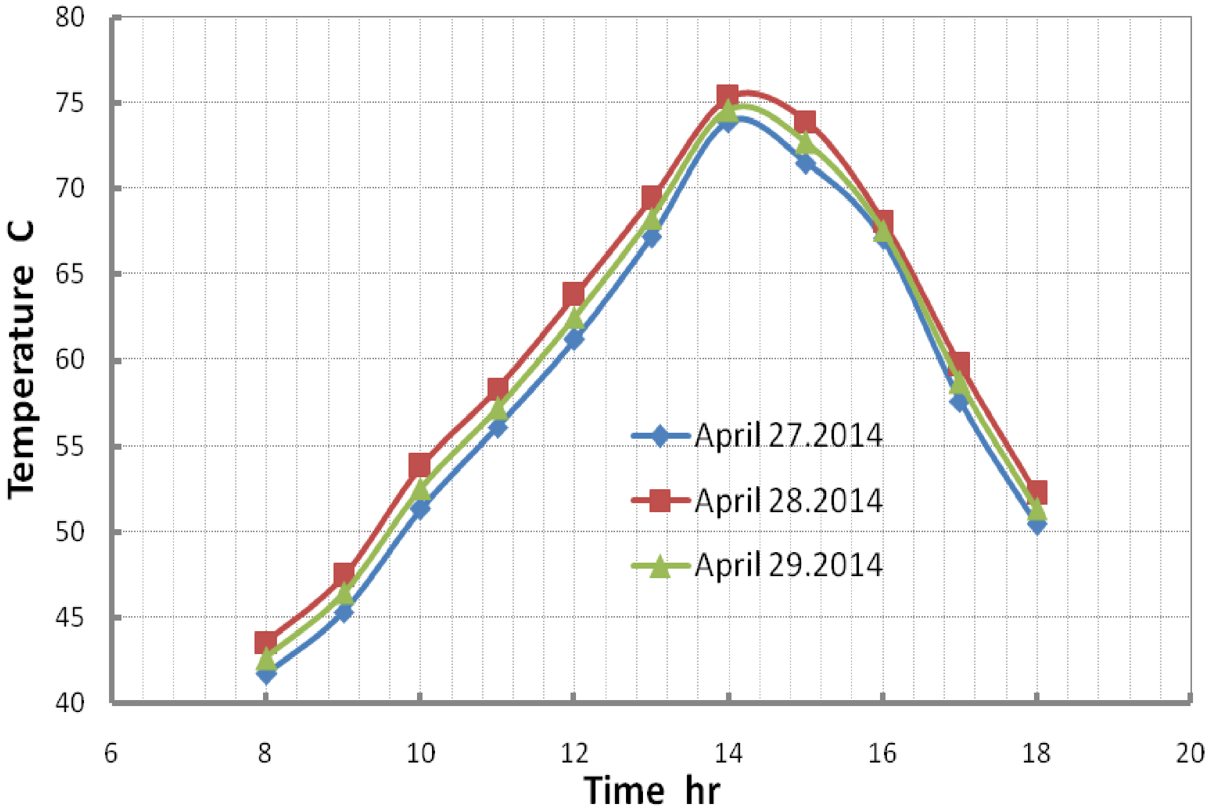

Fig. 42: The temperature variations for the flat plate collector through three days of April 27-29, 2014

Figure 43 shows the temperature variations for the parabolic dish solar collector through two days of April 28-29, 2014. This figure shows that the parabolic dish solar collector gives the highest temperature at the time of 2 PM which reaches to 325°C and the temperature decreases after and before that time with sharp decreases also especially at the day night. For example the differences between the mid-night and 2 PM is approximately 10°C with the solar pond and this difference will very small if the solar pond outside wall be isolated.

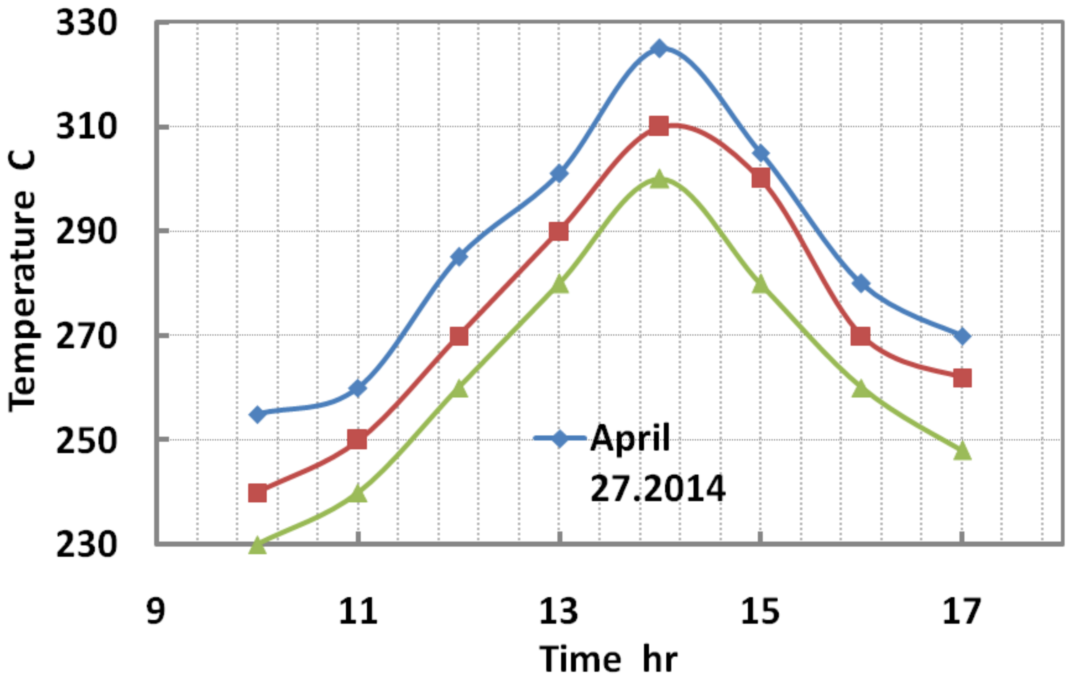

Fig. 43: The temperature variations for the parabolic dish collector through three days of April 28-29, 2014

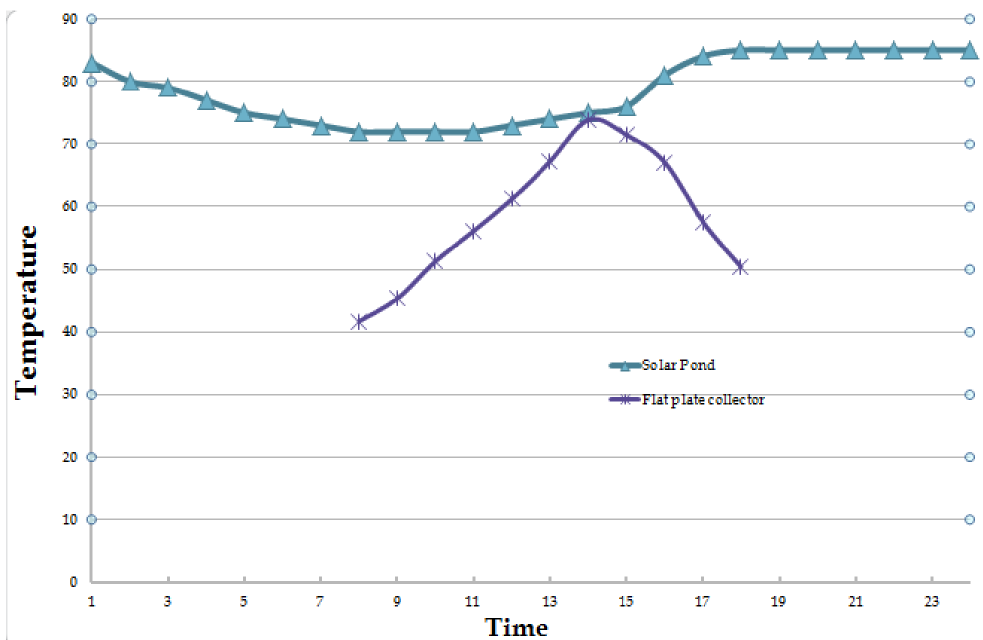

Fig. 44: the highest temperature at the time of 2 PM and the temperature decreases after and before that time with sharp decreases especially at the day night, while with solar pond the temperature decreases not so sharp at the day night.

CHAPTER 5

FEASIBIILITY STUDIES AND MARKET NEEDS

Installing a solar hot water system on an existing home costs about $6,000, depending on the amount of hot water used in the home, the location of the existing hot water tank, and the extent of shade on the roof. Solar hot water collectors can be mounted adjacent to solar electric panels (photovoltaics) on the same roof face, and are significantly smaller. When included in new homes, a system may cost as little as $3,000 because of reduced installation costs.

Solar hot water systems as shown in Figure 44 do more than just save homeowners money. By decreasing natural gas and electricity usage, solar hot water systems make all KSA better off. Global warming and air pollution, from burning natural gas directly as well as in electric power plants, decreases with the use of solar hot water. The significant natural gas savings also reduce KSA's dependence on fuel imports and lower the price of natural gas. The public benefits of solar hot water are discussed in more detail in the next chapter. While solar hot water systems save money over their lifetime, the upfront costs discourage many households from installing them. Appropriate policies, however, can increase public awareness while providing economically beneficial incentives to install the systems, augmenting the benefits to all Californians.

Fig. 45: Homes using the sun for both hot water and electricity

About 38 percent of the natural gas used in California homes is used to heat water.21 KEMA-X-energy, an international consulting and testing company modeled the potential energy savings of various efficiency measures in California homes in 2003. The model used figures for the energy currently being used in water heating to help determine how much energy solar hot water and other technologies could save. Houses that already had the technology or that didn't have any access to sunlight were counted as having no potential for savings. With solar hot water saving an average of 80 percent of water heating energy, the study showed that the technology could save 971 million thermos of natural gas and 1,126 gig watt-hours of electricity per year in homes across the state 22.

Dramatically reducing natural gas consumption with solar hot water has benefits that extend to all Californians. These benefits demonstrate the need for California to encourage the installation of solar hot water heaters in the state. Fully utilizing solar hot water systems in California would reduce demand for natural gas, leading to reduced gas prices. A 2006 report by the American Council for an Energy-Efficient Economy found that a modest drop in natural gas consumption in the Pacific West market (California, Oregon, and Washington) could dramatically reduce the price of natural gas in California in the near and middle term. Specifically, the study found that a 5.1 percent decrease in natural gas usage in the region by 2010 would be accompanied by a 27 and 37 percent drop in wholesale gas prices in Northern and Southern California, respectively.

A parabolic cooker concentrates sunlight. Ordinary sunlight is already dangerous if the sun is viewed directly without protection, so concentrated sunlight can be much more so. The larger the parabola, the greater the danger. Ways of reducing the danger include: Safety rules and Design. However, designing the parabola to avoid a small sharp focal point requires that the cooking vessel have a relatively large surface area to catch the reflected rays. This would make it more likely for someone to be struck by the focused rays, but less damaging if it actually happened. Maximizing the efficiency of absorption by the cooking vessel (it would be expected that making it matt black is the most important thing).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

A. Conclusions

The work suggests building a small-scale of solar desalination system. The first phase of the plant, the pumped seawater is preheated by means of both solar pond and flat plate collector; it is expected to reach 90 Celsius at the end of this phase. Then a parabolic dish collector will be used in the second phase for steam generation. The whole system will include all the necessary pipes, valves, tanks, and pumps. The system is supplied with solar tracking system for the parabolic dish collector.

Three types of solar collectors denoted as solar pond, flat plate collector solar collector, and parabolic dish solar steam generator were designed and manufactured. The necessary test rig for the three different solar collectors was constructed. Using flat plat collector, the heat from the sun is absorbed by black sheet which is exchange the heat to the inner tube of the collector. While, using the parabolic dish collector, heat from the sun is concentrated on black absorber located at the focus point of the reflector in which water is heated to very high temperature to form steam.

The following results were obtained:

1. The flat plate solar collector gives temperature around 75°C in which can used in water-heating systems, space-heating systems, and water heating inside the house as well as in swimming pool.
2. The solar pond collector gives average temperature of 87^{o}C
3. The parabolic dish solar collector gives an average temperature of 325^{o}C.

The complete test rig of the flat plate collectors in combination with parabolic trough solar those used as preheating for the parabolic dish for steam generation and will use in future for sea water desalination.

- In the current work a parabolic trough collector along with its sun tracking system have been designed, manufactured and tested.

- The performance of the parabolic dish collector obtained by testing the manufactured parabolic trough collector in Saudi Arabia is to a great extent less than that of the international standard.
- It is expected to reach better performance by improving the design and manufacturing processes, e.g. adding glass envelope to the collector receiver to reduce thermal losses, and parabola glass mirrors.

B. Recommendations

1. Insolate the solar pond outside walls.
2. Improve concentrator geometry. This will make the largest difference in system efficiency.
3. Improved concentrator, the absorber radius should be decreased to take advantage of the improved optical efficiency. This will decrease radiation and convection.
4. Eliminate the at plate absorber. Use only the cavity absorber and insulate all other surfaces on the receiver.
5. Add a tracking system for the parabolic dish.

7. Appendix

A- Solar Pond

Table 1a: Results of solar pond, April, 22, 2014

LCZ	NCZ	UCZ	Time
72	50	40	8
72	50	40	9
72	51	40	10
72	52	40	11
73	52	41	12
74	53	41	13
75	54	41	14
76	55	42	15
81	55	42	16
84	56	43	17
85	56	44	18
85	56	45	19
85	56	45	20
85	56	45	21
85	56	45	22
85	56	45	23
85	54	45	24
83	52	44	1
80	52	42	2
79	52	42	3
77	52	42	4
75	51	41	5
74	51	41	6
73	51	41	7
72	50	40	8

Table 1b:Results of solar pond, April, 23, 2014

LCZ	NCZ	UCZ	Time
75	55	40	8
75	55	40	9
75	55	41	10
75	55.5	41	11
75	56	42	12
76	57	42	13
77	58	42	14
79	59	43	15
81	60	43	16
84	60	43	17
85	60	44	18
86	60	45	19
86	60	45	20
86	60	45	21
85	60	45	22
84	60	45	23
84	60	45	24
83	59.5	45	1
83	59	44	2
82	59	43	3
81	58	43	4
80	58	43	5
79	57	41	6
78	56	41	7
76	55	40	8

Table 1c:Results of solar pond, April, 24, 2014

LCZ	NCZ	UCZ	Time
75	55	41	8
75	55	41	9
75	55	41	10
75	55.5	42	11
75	56	42	12
76	57	42	13
77	58	43	14
79	59	43.5	15
81	60	44	16
84	61	45	17
85	61	46	18
86	62	46	19
87	62	46	20
87	62	46	21
86	61.5	46	22
85	61	46	23
84	60	46	24
83	59.5	45	1
83	59	44	2
82	59	43	3
81	58	43	4
80	58	42	5
79	57	41	6
78	56	41	7
76	55	40	8

Appendix – B- Flat plate

Table 2: Results of Flat plate, April, 27-29, 2014

Time	27/04	28/04	29/04
8	41.7	43.5	42.6
9	45.3	47.4	46.4
10	51.3	53.8	52.5
11	56.1	58.3	57.2
12	61.2	63.8	62.5
13	67.2	69.4	68.3
14	73.9	75.3	74.6
15	71.5	73.9	72.7
16	67.1	68.1	67.6
17	57.6	59.7	58.7
18	50.4	52.2	51.3

Table C: Results of parabolic dish, April, 27-29, 2014

Time	27/04	28/04	29/04
10	255.0	240.0	230.0
11	260.0	250.0	240.0
12	285.0	270.0	260.0
13	301.0	290.0	280.0
14	325.0	310.0	300.0
15	305.0	300.0	280.0
16	280.0	270.0	260.0
17	270.0	262.0	248.0

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تصميم محطة لتحية المياه باستخدام الطاقة المتجددة في جنوب المملكة العربية السعودية (منطقة جازان)

تعتبر المملكة العربية السعودية كجزء من شبه الجزيرة العربية غنية جدا في مجال الطاقة المتجددة وخاصة الطاقة الشمسية وطاقة الرياح. منطقة جازان التي تقع في المنطقة الجنوبية الغربية للمملكة العربية السعودية تحتل واحدة من المناطق الأعلى في هذه الموارد المتجددة. ولذلك، فإن الاستثمار في مجال الطاقة المتجددة في هذه المنطقة لديها العديد من المزايا. أيضا تعتبر مدينة جازان الاقتصادية واحدة من هذه المزايا . وقد تم تخصيص ثلثي المدينة للصناعات الثقيلة والتي وضعت على أساس الفرص من الصناعات الثانوية المختلفة. القوى العاملة من هذه الصناعات في حاجة لتحليه المياه للمرافق العامة الخاصة بهم. وعلاوة على ذلك تحليه المياه باعتبارها صناعة واعدة يمكن أن تضاف إلى مدينة جازان الاقتصادية لتوفير المياه لكلا القطاعين العام ولري المحاصيل عالية القيمة.

مصادر الطاقة المتجددة لمزيج من الطاقة الشمسية وطاقة الرياح سوف تستخدم في هذه المنطقة لتحليه المياه (مياه البحر والآبار) والذي يعكف على دراسته بعناية فائقة في هذه الدراسة الشاملة . يتم استخدام الطاقة الشمسية في تحليه المياه خلال النهار لوجود الطاقة الشمسية في النهار وتستخدم طاقة الرياح لتوليد الكهرباء لتعويض طاقة الشمس بالليل وبذلك يكون الاستخدام اليومي من الموارد المتجددة.

نستعمل في هذه الدراسة المجمعات الشمسية من مجمعات مقعرة ونصف أسطوانية ومجمعات مركزة ، ويتم استخراج الطاقة من الرياح، في موازاة ذلك، وحفظها لعملية تحليه مياه البحر أثناء الليل. استخدام الطاقة الشمسية وطاقة الرياح على حد سواء يسمح بللاستفادة القصوى من الطاقة المتجددة و يساعد أيضا في الحد من التلوث البيئي والحفاظ على محافظة جازان نظيفة.

يقترح العمل الحالي تصميم وتطوير محطة من أنواع مختلفة من المجمعات الشمسية لتحليه مياه البحر والمياه الجوفية وذلك باستخدام الطاقات المتجددة من الطاقة الشمسية. وهذه المحطة تعمل بثلاث مراحل لعملية تحليه المياه. المرحلة الأولى يتم تسخين مياه البحر عن طريق مجمع شمسي مسطح للطاقة الشمسية والمرحلة الثانية مجمعات شمسية مركزة ، ويعقب ذلك توليد البخار عن طريق الإطباق المكافئ والمرحلة الثالثة هي مرحلة تكثيف البخار بعد مروره عبر عملية التكثيف. أيضا سوف يكون مع هذه المجمعات الشمسية نظام لتتبع الشمس التلقائي للاطباق لزيادة كفاءة الطاقة الشمسية التي يتم تجميعها خلال النهار. سوف يتم دراسة تأثير الأنواع المختلفة من الطباق المجمعة المركزة لأشعة الشمس في نقطة والمجمعة لأشعة الشمس في خط محوري على أداء محطة تحليه المياه المزمع تصميمها وتركيبها في منطقة جازان بعد تركيب المجمعات الشمسية على محركات توجيه شمسية اتوماتيكية لتتبع الأشعة الشمسية . تشير التجارب والحسابات الأولية أن النظام يمكن أن يوفر درجة حرارة 350 درجة مئوية على الأقل مع حوالي 0.11 لتر / ثانية من المياه المحلاة .عن طريق المجمعات الشمسية بدون أجهزة التتبع الشمسي الاتوماتيكية.

CAPSTONE DESIGN PROJECT

Project Submission

and

ABET Criterion 3 a-k Assessment Report

Project Title: Design of a Desalination Plant by Using Renewable Energy in the Southern of KSA

DATE: 13 / 7 / 1435

PROJECT ADVISOR: Prof. Dr. Ahmed Sayed Ahmed Hassan

Dr. Ali Saeed Z. Al-Shahrani

Team Leader: Wajdi W. Dosary

Team Members2. Mohamed H. Ayoub, Osama Zakri,

Ismail A. Akish, and Abdulrahman Aljayzani

Design Project Information

Percentage of project Content- Engineering Science %	40%
Percentage of project Content- Engineering Design %	60%
Other content %	
All fields must be added to 100%	
Please indicate if this is your initial project declaration or final project form	☐ Project Initial Start Version ☐ Final Project Submission Version

Do you plan to use this project as your capstone design project?

Mechanism for Design Credit

☐ Projects in Engineering Design
☐ Independent studies in Engineering
☐ Engineering Special Topics

Fill in how you fulfill the ABET Engineering Criteria Program Educational Outcomes listed below

Outcome (a), *An ability to apply knowledge of mathematics, science, and engineering fundamentals.*	The project included the engineering fundamental of: thermodynamics, fluid mechanics, heat transfer, and renewable energy.
Outcome (b). *An ability to design and conduct experiments, and to critically analyze and interpret data.*	The project includes design and fabricate a solar collectors and desalination system and conduct an experimental test rig.
Outcome (c). *An ability to design a system, component or process to meet desired needs within realistic constraints such as economic, Environmental, Social, political, ethical, health and safety, manufacturability, and sustainability*	The project includes a design components of solar energy system such as solar pond, flat plate, parabolic dish, evaporation system condenser, piping system, valves, pump and tank.
Outcome (d). *An ability to function in multi-disciplinary teams.*	
Outcome (e). *An ability to identify, formulate and solve engineering problems.*	The students have to calculate the heat transfer rate and thermal efficiency of the system
Outcome (f). *An understanding of professional and ethical responsibility.*	
Outcome (g). *An ability for effective oral and written communication.*	*Writing the final report of the project.*
Outcome (h). *The broad education necessary to understand the impact of engineering solutions in a global economics, environmental and societal context .*	Since the solar energy is clean and low cost renewable energy , therefore using the solar energy as energy source is economic and safe the environment.

Outcome (i).
A recognition of the need for, and an ability to engage in life-long learning.

The system developed in this project is need to redesign in order to achieve higher efficiency.

Outcome (j).
A knowledge of contemporary issues.

Study of other methods of desalination and made comparison between the different methods to obtain the suitable method of sea water desalination.

Outcome (k).
An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

This project consists of fabrication of solar pond, different solar collectors, condenser and evaporator, piping system that includes of many engineering tools.

By signing below certify that this work is your own and fulfills the criteria described above

Student Team Signatures

1. Wajdi W. Dosary 2. Mohamed H. Ayoub
3. Osama Zakri 4. Ismail A. Akish
5. Abdulrahman Aljayzani

Project Advisor Signature ________________________

Date

College Coordinator of Capstone Projects ________________________

Approved By

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