



*Thesis Topic:*

**Using Solar Evaporation Ponds for the Treatment of  
the Desalination Plants Brine**  
**(Gaza Strip Case Study)**

Submitted By::

**Amal Waleed Qarroot**

Supervised By:

**Dr. Yunes Khalil Mogheir**

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A Thesis submitted in final fulfillment of the requirement for Degree of Master of  
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## **DEDICATION**

*I would like to dedicate this work to My Beloved Parents, My husband, My Sisters and  
My Brothers*

## **ACKNOWLEDGMENTS**

Praise is to Allah the most compassionate the most merciful for giving me persistence and potency to accomplish this study.

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*Amal W. A. Qarroot  
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## ABSTRACT

In this research, An experimental shallow solar pond (SSP) having a surface area of  $1*1\text{ m}^2$  and depth of 20 cm has been built. Solar evaporation ponds are especially suitable to dispose of reject brine from inland desalination plants in arid and semi-arid areas due to the abundance of solar energy. Nearly all forms of salt production require evaporation of water to concentrate brine and ultimately produce salt crystals.

In this study, three scenarios have been used (1): Solar pond without using any mirror in 17 July 2015, (2): Solar pond using one reflector mirror; this scenario extending for five days from 18 to 22 July 2015, (3): Solar pond using two reflector mirrors extending for five days from 12 to 16 July 2015.

Mirrors, which are movable for five different angles that makes with horizontal, have been used as reflectors in order to increase the thermal energy for the surface of the solar pond during the day.

This research has been studied the main factors affecting the evaporation rate which are relative humidity, wind speed, ambient air temperature and solar radiation.

The results showed that the little of decreasing evaporation rate was observed by increasing relative humidity and maximum evaporation rate was observed at relative humidity of 67.6%, while slight increasing of evaporation rate was observed by increasing ambient air temperature, evaporation rate appears to decrease slightly as wind speed increases and gradual increasing of evaporation rate with increasing solar radiation. Comparisons between experimental and theoretical results have been performed which good agreement has been achieved.

Results showed that evaporation rate increases with decreasing the mirror's angle that makes with horizontal  $\beta$ . It was concluded that using two mirrors are very effective more than using one mirror when they are used as reflectors and that the best performance of the evaporation can be achieved when the mirrors are employed as reflectors.

In conclusion, this system proved to be promising and using one mirror and two mirrors reduced the solar pond area and hence reduced area needed for brine evaporation in Gaza strip desalination plants then can be further developed to achieve better results using large scale solar pond.

**Key words:** Brine, solar system, Shallow solar ponds.

## ملخص الدراسة

في هذا البحث تم بناء بركة تبخير باستخدام الطاقة الشمسية بمساحة 1 متر مربع وعمق 20 سم حيث تعتبر أحواض التبخير الشمسى مناسبة جداً خاصة للتخلص من الماء شديد الملوحة الناتج من محطات تحلية المياه الداخلية في المناطق الفاحلة وشبه الفاحلة بسبب وفرة الطاقة الشمسية. تقريباً جميع أشكال إنتاج الملح تتطلب تبخير المحلول الملحي بحيث ينبع في نهاية المطاف بلورات الملح.

في هذه الدراسة، تم استخدام ثلاثة سيناريوهات (1): البركة الشمسية دون استخدام أي مرآة بتاريخ 17 يوليو 2015، (2): البركة الشمسية باستخدام مرآة واحدة عاكسة لأشعة الشمس من الفترة 18 يوليو 2015 وحتى 22 يوليو 2015، (3): البركة الشمسية باستخدام اثنين من المرآيا العاكسة من الفترة 12 يوليو 2015 وحتى 16 يوليو 2015. حيث تم تركيب المرآيا باستخدام نظام يدوي ليتم التحكم بحركتها حسب اختلاف الزوايا لتصبح أكثر فاعلية بانعكاس وزيادة الطاقة الحرارية على سطح المياه شديدة الملوحة الموجودة داخل بركة التبخير.

وقد نتت دراسة العوامل الرئيسية التي تؤثر على معدل الإشعاع الشمسي ومقدار سرعة الرياح ودرجة حرارة الجو وأيضاً الرطوبة النسبية. وأظهرت النتائج أنه كلما زادت الرطوبة النسبية يقل معدل التبخر للمياه شديدة الملوحة ومعدل التبخير يصل للقيمة العظمى عندما كانت الرطوبة النسبية  $67.6\%$  ، وزيادة طفيفة في معدل التبخر لوحظ من خلال زيادة درجة حرارة الجو، أيضاً ينخفض معدل التبخير كما زادت سرعة الرياح وزيادة تدريجية في معدل التبخر مع زيادة الإشعاع الشمسي. وقد أجريت مقارنات بين النتائج التجريبية والنظرية وكانت النتيجة مرضية ومتقاربة.

وأظهرت النتائج أن معدل التبخير يزداد مع تناقص زاوية بين المرأة والخط الأفقي. وكانت الخلاصة أن استخدام اثنين من المرآيا فعال جداً أكثر من استخدام مرآة واحدة عندما يتم استخدامها كعاكسات وأن أفضل أداء البركة يمكن أن يتحقق عندما تستخدم المرآيا كعاكسات.

في الختام ثبت هذا النظام بأنه نظام واعد ويحقق النتيجة المرجوة وهي أن استخدام المرآيا يقلل من المساحة الازمة من الأرضي في قطاع غزة لتبخر المياه المالحة في محطات التحلية قطاع غزة من خلال تجميع الطاقة الشمسية وعكستها باستخدام المرآيا مباشرة على سطح برك التبخير ومن ثم يمكن مواصلة تطويرها من أجل تحقيق نتائج أفضل باستخدام نطاق واسع للبركة الشمسية.

**الكلمات الدلالية:** برك التبخير، الطاقة الشمسية، المياه شديدة الملوحة

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## List of Abbreviations

### Nomenclature

$H_{hs}$	Global solar radiation flux incident on the horizontal surface ( $\text{W/m}^2$ )
$L_r$	Solar radiation reflective losses (%)
$m_w$	The mass (kg) of the water evaporated
$m_s$	The mass (kg) of the salt crystallized
$S$	The initial salt concentration of the brine in wt% NaCl
$E$	The evaporation rate expressed as mm/day
$\Delta$	The gradient of the vapor pressure-temperature curve
$R_n$	The net solar radiation
$f(u)$	A function of wind speed
$e_s$	The saturation vapor pressure of water
$e$	Ambient water vapor pressure
$T$	Mean daily air temperature, $^\circ\text{C}$
$T_{\max}$	Maximum daily air temperature, $^\circ\text{C}$
$T_{\min}$	Minimum daily air temperature, $^\circ\text{C}$
$e_T$	Saturation vapor pressure at the air temperature $T$ , kPa
$a_w$	Water activity coefficient
$m$	The concentration of sodium chloride in moles per liter of water
$z$	Height above sea level (m)
$p$	Atmospheric pressure (kpa)
$\gamma$	Psychrometric constant, $\text{kPa } ^\circ\text{C}^{-1}$
$\lambda$	Latent heat of vaporization, 2.45, $\text{MJ kg}^{-1}$
$c_p$	Specific heat at constant pressure, $1.013 \cdot 10^{-3}$ , $\text{MJ kg}^{-1}\text{ }^\circ\text{C}^{-1}$
$\varepsilon$	Ratio molecular weight of water vapour/dry air = 0.622
$H_r$	The relative humidity (%)
$e_{(T_{\min})}$	Saturation vapour pressure at daily minimum temperature, kPa
$e_{(T_{\max})}$	Saturation vapour pressure at daily maximum temperature, kPa
$H_{r\max}$	Maximum relative humidity, %
$H_{r\min}$	Minimum relative humidity, %
$u_2$	Wind speed 2 m above the ground surface, $\text{m s}^{-1}$
$u_h$	Measured wind speed $h$ m above the ground surface, $\text{m s}^{-1}$
$h$	Height of the measurement above the ground surface, m
$\delta$	The solar declination angle (rad)
$\omega$	The hour angle
$\varphi$	The latitude Angle
$\theta$	The solar zenith angle
$\omega$	The hour angle
$\alpha$	The altitude angle
$Z$	The solar azimuth angle
$R_a$	Extraterrestrial radiation, $\text{MJ m}^{-2} \text{ day}^{-1}$
$G_{sc}$	$0.0820 \text{ MJ m}^{-2} \text{ min}^{-1}$
$d_r$	The inverse relative Earth-Sun distance
$\omega_s$	The sunset hour angle (rad)
$J$	Number of the day in the year between 1 (1 January) and 365 or 366 (31 December)
$R_s$	The solar radiation ( $\text{MJ m}^{-2} \text{ day}^{-1}$ )
$n$	The actual duration of sunshine (hours)
$N$	The maximum possible amount of sunshine (hours)
$a_s$	Regression parameter with recommended value of 0.25
$b_s$	Regression parameter with recommended value 0.50

$R_{ns}$	The net solar or shortwave radiation ( $\text{MJ m}^{-2}\text{day}^{-1}$ )
$R_{nl}$	Net outgoing long wave radiation, $\text{MJ m}^{-2} \text{day}^{-1}$
$a$	The albedo of the surface or canopy reflection coefficient
$\sigma$	The Stefan-Boltzmann constant ( $4.903 \cdot 10^{-9} \text{ MJ K}^{-4} \text{ m}^{-2} \text{ day}^{-1}$ )
$T_{\max}$	K maximum absolute temperature during the 24-hour period [ $K = {}^\circ\text{C} + 273.16$ ]
$T_{\min}$	K minimum absolute temperature during the 24-hour period [ $K = {}^\circ\text{C} + 273.16$ ]
$R_s$	The incoming solar radiation ( $\text{MJ m}^{-2} \text{day}^{-1}$ )
$R_a$	The extraterrestrial radiation ( $\text{MJ m}^{-2} \text{day}^{-1}$ )
$\alpha$	The angle between the horizontal surface and the incident light arriving at any hour of any day of the year
$XY$	The front side of the projected area of the reflector normal to the incident light
$C$	The angle between XY and the reflector and it is a function of time
$ML$	The side length of the reflector
$SM$	The projection area of the reflector normal to the incident light
$a$	The length of one side of the pond or the length of the reflector
$G$	The amount of the solar energy which will be reflected by the t reflector into the solar pond
$B$	The amount of the solar energy falling on one-meter square area perpendicular to the incident light per unit time
$U$	The amount of the solar energy which will fall on one-meter square area of the solar pond in per unit time
$F$	The angle between the light beams coming from reflectors and the normal of the surface of the solar pond
$\beta$	The mirror angle makes with horizontal
$A_p$	Bottom surface area of solar pond

## Subscripts

$Ucz$	Upper Convective Zone
$Ncz$	Non-Convective Zone
$Lcz$	Lower Convective Zone
$EP$	Evaporation pond
$LST$	Local standard time or clock time for that time zone
$Long$	Local longitude at the position of interest
$LSTM$	Local longitude of standard time meridian
$WRC$	The World Radiation Center
$LHS$	Left hand side reflector
$RHS$	Right hand side reflector
$SSP$	Shallow solar pond

# **Chapter 1 : Introduction**

## **1.1 Background**

The desalination of seawater is a common method for providing fresh drinking water in The Gaza Strip as a solution to increase water resources . However, the disposal of the brines generated by the desalination process poses significant environmental issues and negative impact, due to the high concentrations of salts and increases in the concentration of transition and heavy metals. This brine is usually discharged to inland water bodies or to the sea and constitutes a threat to ecosystems and species. In the last decade, new demonstration projects have been addressed to achieve an effluent volume reduction by either solar evaporation ponds or thermal evaporation. Brine volume reduction by evaporation techniques results in a solid product that can more easily be disposed of comparing to the original concentrate, whereas the low salinity effluent can be reused to increase the water production ratio or it can be directly discharged into surface or ground water bodies.

Due to the environmental problems that brine disposal can cause and high disposal cost, many technologies have been developed for recovery to avoid the disposal into the sea. Examples are renewable energy generation and use in evaporation ponds to produce salt or chemicals for industry. Nevertheless, more investigation is needed to reduce brine quantity and to allow recovery and reuse of brine.

Because of the declining economic situation, the Gaza Strip is suffering from energy crisis. On the other hand, solar energy is a renewable resource; it is abundant, inexhaustible and free.

Solar evaporation consists of leaving brine in shallow evaporation ponds, where water evaporates naturally thanks to the sun's energy. Salt is left in the evaporation ponds or is taken out for disposal. Evaporation ponds are relatively easy to construct, while requiring low maintenance and little operator attention compared to mechanical systems. In addition, no mechanical equipment is required, except for the pump that conveys the brine to the pond, which keeps low operating costs. Nevertheless, evaporation ponds for disposal of concentrate from desalination plants need to be constructed as per the design and maintained and operated properly so as not to create any environmental problem, especially with regard to groundwater pollution.

Solar evaporation is a suitable technology to be used in arid regions where land is available. Land is crucial because shallow ponds (ranging from 25 to 45 cm) are optimal for maximizing the rate of evaporation. However, due to the quantity of terrain needed to treat large volumes, evaporation ponds have limited use, especially in wet areas, where land purchase can dramatically raise capital costs.

Evaporation ponds are most effective in arid and semiarid climates having high net evaporation rates, the Gaza Strip suffers from a lack of available land areas for the use of evaporation ponds, so high net evaporation rates decrease the pond area required because evaporation occurs in less time. A major advantage for constructing evaporation ponds in the Gaza Strip is the higher evaporation rates due to the high solar energy available throughout the year.

Therefore, this paper presents the testing results of an attempt to design and construct a shallow solar pond utilizing the local raw materials and expertise.

## 1.2 Problem statement

Desalination has become an important source of drinking water in the Gaza Strip , but the major disadvantage of the desalination process is the huge amount of brine and its negative impact as a result of its high salinity. Therefore, further research is needed for introducing environmentally friendly and economically viable management options for brines disposal.

As well as the Gaza Strip suffering from electrical energy shortage. Therefore, the use of solar energy for evaporated brine can reduce electrical energy consumption .

Solar evaporation is a suitable technology to be used in arid regions where land is available. However, due to the quantity of terrain needed to treat large volumes of brine water , evaporation ponds may have limited use in the Gaza Strip where land is not available. By increasing the evaporation rate, the pond land may reduce. Therefore, the use of available solar energy in Gaza could be appropriate option to increase the evaporation rate. Through evaporation ponds, solar energy evaporates water from the concentrate, leaving behind precipitated salts that are ultimately disposed in landfills or use in industry.

## 1.3 Justification of the Study

The Gaza Strip is semi-arid as well coastal region. Figure 1.1 shows the annual monthly average variation in solar radiation in the three Climate zones of the Palestinian Territories[1]. Solar insulation has an annual average of  $5.4 \text{ kWh/m}^2\text{.day}$ , which fluctuates significantly during the day and all over the year, and approximately 2860 mean-hour sunshine throughout the year. The measured values in the different areas show that the annual average insulation values are about  $5.24 \text{ kWh/m}^2\text{.day}$ ,  $5.63 \text{ kWh/m}^2\text{.day}$ ,  $5.38 \text{ kWh/m}^2\text{.day}$  in the coastal area, hilly area and Jordan valley respectively. The average annual global horizontal radiation for all stations is  $2017 \text{ kWh m}^{-2} \text{ year}^{-1}$ [2].

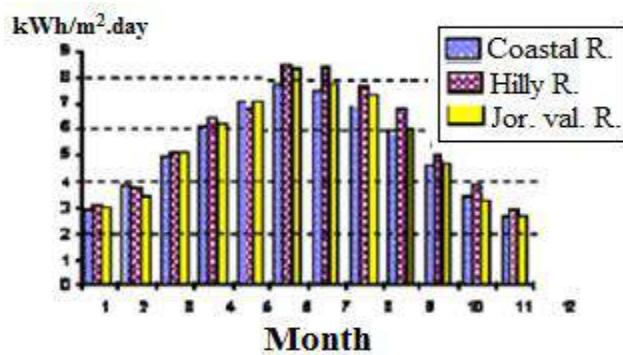


Figure 1.1: Annual monthly average variations in solar radiation in the three climate zones of the Palestinian Territories [1]

## **1.4 Goal**

The main goal of the study is to utilize solar energy for brine water evaporation using shallow solar pond and optimize a model suitable for the Gaza Strip.

## **1.5 Objectives**

The objectives of this research are:

- 1- To study the efficiency of concentrated-solar technology systems using different combination of mirrors or lenses with manual tracking system.
- 2- To study the effect of some variables such as solar radiation, wind speed, ambient air temperature and relative humidity on rate of evaporation.
- 3- To provides the engineering analyses and technical details to support design of the evaporation pond for the brine water treatment.
- 4- To lead to the production of “final useful products of salt NaCl” by the complete separation of two phases; a solid and a liquid.
- 5- To study and analyzes the produced dry salt (solid phase) that will be easily handled and commercially utilized.

## **1.6 Methodology**

It is intended to achieve the objectives of the study by the following steps:

### **a. Literature review**

Revision of accessible references as books, studies and researches relative to the topic of this research which may include brine water management, solar energy, evaporation pond in the Gaza Strip.

### **b. Data collection**

Data gathering from relevant institution and ministries that includes details and time series data about different influenced parameters of water quality such as electrical conductivity, TDS and others .

### **c. Sample collection**

Brine Water samples collection from the desalination plant located on the Gaza Strip governorates and divided basis on the concentration of sodium chloride and TDS.

Water samples from the sea that enters the desalination plants were collected from the Gaza sea .

### **d. Experiment**

1- Due to the nature of solar energy, two components are required to have a functional solar energy generator. These two components are a collector and a storage unit. The

collector simply collects the radiation that falls on it and converts a fraction of it to other forms of energy (either electricity and heat or heat alone).

In this research heat energy only were utilized.

2- System Component: the system consists of:

- Construction of small shallow solar evaporation pond which was made of a galvanized iron reservoir containing about  $0.25 \text{ m}^3$  of brine water rejected from desalination plant .
- Concentrating Solar Power (CSP) by using mirrors to concentrate and reflect (focus) the sun's light energy onto a small area and convert it into heat to evaporate brine water.
- Using manual tracking mechanism which provides different angles which mirrors makes with horizontal .

3- The brine reject is concentrated causing precipitation of salt crystals as the solubility limit is reached. Through evaporation ponds, solar energy evaporates water from the concentrate, leaving behind precipitated salts that are ultimately disposed in landfills or use in industry.

4- Pure salt (NaCl) production :

- Evaporation can be used to concentrate one of the primary components (NaCl) and obtain a suitable raw material for industrial applications.
- Samples were taken from seawater reverse osmosis (SWRO) rejected disposal, Seawater RO plants operating at 50% recovery produce a brine waste stream having about 70,000 ppm salinity.
- First, the pH needs to be measured in every sample using a glass electrode. The NaCl,  $\text{SO}_4^{2-}$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  levels in the samples were analyzed using different analytical methods.

## 1.7 Research Structure

This research consists of six chapters, as follows:

### **Chapter One: Introduction**

This chapter includes background about the study area of the Gaza Strip, goal and objectives of thesis.

### **Chapter Two: Literature Review**

Revision of accessible references as books, studies and researches relative to the topic of this research which include brine water management, solar energy, evaporation pond in Gaza Strip .

### **Chapter Three: Theoretical Background.**

This chapter includes the equations used to determine the evaporation rate with several different parameters and shows the methodology for this process.

**Chapter Four: Materials and Methods.**

Chapter four describes the construction of shallow solar pond using locally materials and the methods used for the research.

**Chapter Five: Discussion and Analysis.**

All data used in chapter 3 results a group of models that were analyzed and discussed.

**Chapter Six: Conclusions and Recommendations.**

## **Chapter 2 : Literature review**

### **2.1 Definition of solar ponds:**

A solar pond is an effective way of capturing and storing solar energy over extended period. Generally speaking, a solar pond is a natural or artificial tank under sunlight illumination, which has heat absorption and energy storage capabilities. It has been studied around the world for about half century.

Velmurugan and Srithar reviewed various designs of solar pond, prospects to improve performance, factors affecting performance, mode of heat extraction, theoretical simulation, measurement of parameters, economic analysis and its applications [3]. Angeli et al. investigated the problem of development of salt concentration in a solar pond with thermo diffusion contribution using Computational Fluid Dynamics [4].

Agha et al. presented the results of a simple mathematical model for predicting the ratio of the evaporation pond (EP) area to that of a Salt Gradient Pond Area. The EP idea gives an attractive method of salt recycling by evaporation especially in areas of high rates of evaporation and low rates of rain [5].

Agha et al. applied the evaporation pond idea to two types of water flushing (fresh water and sea water) under different scenarios and predicted the quantities of brine provided by the evaporation pond for both cases of surface water flushing [6].

Andrews and Akbarzadeh suggested an alternative method of heat extraction from salinity-gradient solar ponds with the aim of increasing the overall energy efficiency of collecting solar radiation, storing heat and delivering this heat to an application [7]. Husain et al. determined the optimum size of the non-convective zone for fast warm-up to increase the efficiency of the pond and analyzed the possibility of achieving fast warm-up and maximum heat collection capacity. They concluded that the ponds should be designed for warm up criterion than for steady state criterion [8].

### **2.2 Types of solar ponds**

Solar ponds represent one of the simplest methods for directly collecting solar irradiation and converting it to thermal energy. Moreover, it is a solar power collector and a thermal storage unit at the same time. All natural ponds and lakes convert solar radiation into heat although most of that energy is lost to the atmosphere mainly as a result of convection and evaporation. The principle of the salinity gradient solar pond, on the other hand , is to prevent vertical convection and/or evaporation (according to the type of solar pond) [9]. Based on the convection behavior of the saline solution in solar ponds, they may be classified into two main categories: non-convecting and convecting solar ponds. These types will be discussed briefly in the following sections.

### **2.2.1 Non-convecting Solar Ponds**

This type of pond suppresses heat loss by preventing convection currents from developing within the liquid body. They usually consist of three saline water layers, where the salt concentration is highest in the bottom layer and lowest in the shallow surface layer.

The concept of this technique is based on collecting and storing the solar radiation as heat in a relatively small pond in order to raise the water temperature. In nature, when the sun's rays fall on surface of a lake or pond, the water molecules absorb the heat and the temperature then rises accordingly. Therefore, the water in the bottom becomes warmer then it rises to the surface and loses its heat to the atmosphere, this phenomenon is called convection. However, the solar pond technology inhibits this phenomenon by dissolving salt into the bottom layer of the pond, making the molecules too heavy to rise to the surface, even when hot. Thus the temperature gain in the bottom layer is cumulative, and this can increase the temperature there to more than 100°C. Once a high temperature is obtained, the bottom layer can be used as a heat source to provide continuous heat through an internal or external heat exchanger at any time of the year, regardless of season.

Non-convective solar ponds are simple in design and can be constructed at reasonable cost; they can provide heat for domestic, agricultural, industrial and desalination purposes and they can also generate power. Non-convective solar ponds can be subdivided into two main types: salinity gradient and membrane ponds.

#### **2.2.1.1 Salinity Gradient Solar Pond (SGSP)**

The salt gradient solar pond is typically 1–2 m deep and the bottom is painted black as shown in Fig. 2.1. The convection currents that normally develop due to the presence of hot water at the bottom and cold water at the top are prevented by the presence of strong density gradient from bottom to top. This density gradient is obtained by using a high concentration of suitable salts such as NaCl at the bottom of the pond and negligible concentration at the top. The thermal conductivity of the salt solution, which is even less than that of stagnant water, decreases with the increase of salinity and thus acts as an insulating layer [10].

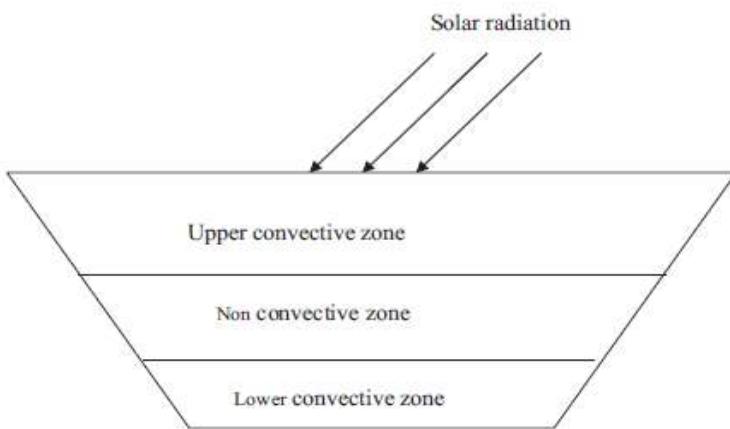


Figure 2.1. Diagram of the salt gradient solar pond.

A typical salinity-gradient solar pond consists of three main zones (as shown in Figure 2.2):

a- The Upper Convecting Zone (UCZ); this part is sometimes called the surface layer. This involves the least cost, has the lowest level of salinity, and its temperature is close to ambient temperature. The thickness of this zone is typically 0.3m and it should be kept as shallow as possible. The cost of constructing the UCZ is usually neglected, as it can be constructed and operationally maintained through the use of any low-salinity water such as fresh, brackish water or seawater. This layer is essential for preventing the lower layers from being exposed to evaporation, wind effects and falling impurities.

b- The Non-Convection Zone (NCZ); this region can be also called the gradient zone or the middle layer with thickness ranges from 0.6 to 1.0 m which acts as an insulating layer of the pond. It is located between the upper and the lower zones of the pond. In the NCZ, the brine salinity increases gradually with depth, thus its density also increases with depth. The heat in this layer cannot transmit by convection. Therefore, the NCZ, as the key element of salinity gradient solar ponds, has the function of preventing heat loss from the storage zone. In the NCZ, the temperature is not homogeneous and increases gradually with depth to form a temperature gradient. The thickness of the gradient layer depends on the desired temperature, solar transmission properties and thermal conductance of water. If the salinity gradient is large enough, the NCZ exhibits a convection phenomenon.

c- The Lower Convecting or Storage Zone (LCZ); this is a homogenous layer and has considerably high salinity and high temperature. LCZ has the function of absorbing and storing the heat. This is also useful heat is usually extracted from this layer for different applications. As the LCZ's depth increases, the heat storage unit increases and the temperature variation decreases.

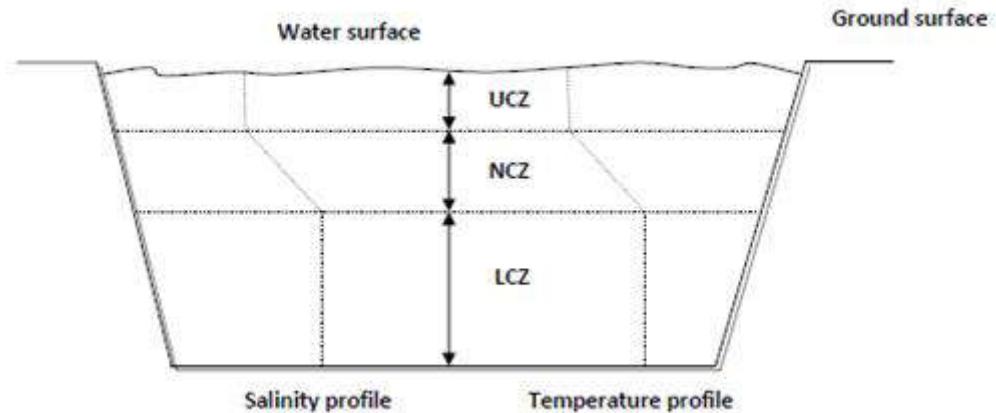


Figure 2.2 :Salinity and temperature profiles through the salinity gradient solar pond zones.

Any increase in the thickness of the lower convective zone in a salinity gradient solar pond decreases both the maximum obtained temperature and the heat loss from this zone, and it increases the maximum storage heat in the lower zone as shown in table 2.1. Although most research has reported that the optimal thickness for the LCZ is about 1m, it was concluded by German and Muntasser [11] that the optimal thickness of the storage zone is 4m. The depth of this zone depends on the purpose of the pond and on the method of heat extraction from this layer. For example, it should be kept as

shallow as 0.5m or even less when high temperatures are required and the withdrawal of heat is in operation; this is to control the steep temperature fluctuation that typifies an LCZ with a very shallow depth. For this reason, Hall et al. [12] stated that the depth of this layer should not be less than 0.5m if the pond is not in operational mode in order to avoid the effects of this rapid temperature variation on the salinity gradient solar pond's stability.

Table 2.1: The effect of gradient zone depth on storage zone thermal performance of a solar pond with 3m total depth[13].

Depth of NCZ (m)	Total radiation (GJ)	Peak temp. (C)	Max. stored energy (GJ)	Surface heat loss (GJ)
1	135	53	65.5	90.9
1.5	115.3	61	51	70.9
2	100.3	67	40.8	61.8
2.5	89.1	82	25.4	58.6

GJ = Giga Joules

If  $H_{hs}$  amount of solar radiation is incident on the horizontal top surface of the solar pond and around  $L_r$  percentage of solar radiation is reflected back to the atmosphere, then  $(H_{hs} - L_r \times H_{hs})$  amount of solar radiation penetrates the top surface of the solar pond. And this amount of solar radiation is gradually absorbed by the water along the depth of the solar pond. As shown in Fig. 2.3,  $h_{ucz}$  is the amount of solar radiation that is absorbed by the water in the UCZ,  $h_{ncz}$  is the amount of solar radiation that is absorbed by the water in the NCZ and  $h_{lcz}$  is the amount of solar radiation that is absorbed in the LCZ. The solar radiation that is absorbed in the three layers of the solar pond is converted to heat. Part of this heat is lost to the atmosphere and part is lost to the ground. The amount of heat that is stored in the LCZ and NCZ is available for extraction and this amount of heat is responsible for the temperature gradient formation in the solar pond.

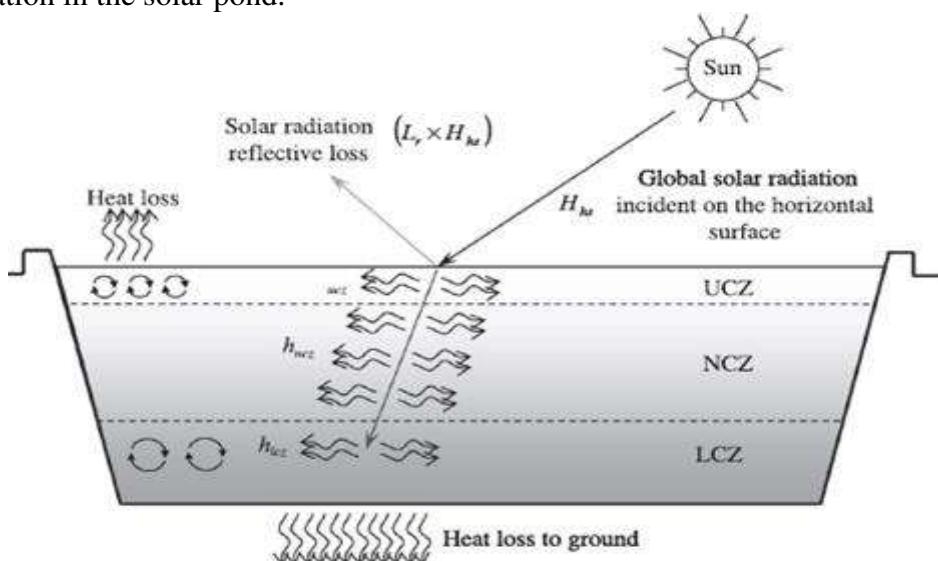


Figure 2.3 Schematic diagram of salinity gradient solar pond.

In order to improve the performance of the conventional salt gradient solar pond (CSGSP), the concept of the advanced solar pond (ASP) was introduced by Osdor [14]. There are two main features that distinguish the ASP in comparison with the CSGSP: (i) the overall salinity of the pond is increased, and (ii) an additional (stratified) flowing layer is established in the lower part of the gradient zone (GZ). Increased salinity is proposed primarily for the surface layer in order to reduce evaporative heat loss; however, this requires the salinity in the rest of the pond to be increased as well. In order to maintain stability, the stratified flowing layer is used for additional heat extraction, similar to the flow that would be established in the lower convective zone (LCZ) for the same purpose. Therefore, heat is extracted over a larger depth of the pond and heat is also recovered which might otherwise have been conducted upward out of the LCZ [15].

#### **2.2.1.1 Establishment and maintenance of salt gradient**

The salt concentration gradient in the pond can be generated by various methods dependent on local requirement [16]. These methods include natural diffusion, stacking, redistribution and falling.

In the natural diffusion method, the upper half is filled with water, top and bottom concentrations are maintained constant by regularly washing the surface and adding salt in the bottom. Owing to the upward diffusion of salt, a salinity gradient will be established. This is a very slow method of establishing the salt gradient and should be considered if the pond is very large, or if the starting time could be unlimited [17].

Stacking involves the filling of the pond with a storage layer of high concentration solution and several other layers of salt solutions of differing concentration. The concentration of salt in successive layers is changed in steps from near saturation at the bottom to fresh water at the top. For a typical pond of about 1 m depth, one might use about 10 layers. The turbulent mixing generated during filling and continuous molecular diffusion modifies the stepwise type concentration profile into a nearly linear concentration profile [18,19]. The practical approach for stacking used in most solar ponds is that the bottom layer is filled first and successively lighter layers are floated upon the lower denser layers. However, some experimental ponds in Australia [20,21] have been built by injecting in the bottom successively denser layers which lifted the lighter layers filled previously.

Redistribution is considered to be the most convenient for larger ponds [22,23], when fresh water is injected at some level into homogeneous brine, it stirs and uniformly dilutes the brine from a few centimeters below the injection level to the surface. Hence, the artificial pond is filled with high salinity brine to half of its total depth and then fresh water is added through a diffuser. Initially, the diffuser is placed at the bottom and the water is added in the pond, flowing in as under current and the level in the pond increases. The diffuser is moved upward continuously or in steps. Timing of the movement is so adjusted that the diffuser as well as the water surface reaches the final level at same time. At the completion of this process we have a nearly uniform salt concentration gradient in the pond [17].

The salt gradient can also be maintained by periodically adding of a saturated salt solution at the bottom and washing the surface with fresh water [24]. A more efficient approach, which does not require the continual addition of salt, is the falling pond concept [25,26], wherein, hot brine is withdrawn from the bottom layer without causing disturbance to the layer above. This is possible, since in a fluid system stratified with a density gradient, selective flow of the bottom layer can be accomplished without requiring a mechanical separation between the flowing and stable regions of the system [27–29]. The hot brine withdrawn from the solar pond is passed through the flash evaporator to remove some of its water. The solution now having a high concentration and smaller volume is reinjected in the pond bottom and the removed water is replaced into the surface layer, consequently, the concentration gradient would be maintained. The fall in surface level due to evaporation is also restored by the addition of fresh water to keep both the pond depth and the surface concentration constant. In this process, the gradient tends to be displaced downwards. It is acute that the brine circulation rate and the location of the suction diffuser with respect to the lower interface must be selected carefully in such a manner that withdrawal and re-injection of brine does not disturb the salinity gradient [30].

### **2.2.1.1.2 The stability of the pond**

The density of liquid in the solar pond depends on, the salt concentration (C) and temperature (T) of the liquid. Weinberger [31] indicated that there will be no vertical thermal convection or the pond will be stable when the density gradient on account of the salt concentration gradient is greater than the negative density gradient produced by the temperature gradient (or the total derivative of density with respect to depth) is greater than or equal to zero, [32] i.e.:

$$\frac{d\rho}{dx} = \frac{\partial \rho}{\partial C} \cdot \frac{\partial C}{\partial x} \geq - \frac{\partial \rho}{\partial T} \cdot \frac{\partial T}{\partial x} \quad (2.1)$$

where  $\rho$  is the density of the liquid and  $X$  is the depth of the water (measured positive going downward).

The gradient layer consists of multi sup-layers in which each sup-layer is heavier and hotter than the ones above it. This stratification can make the saline molecules heavy enough to not obey to the convection phenomenon. In other words, the whole gradient zone can be established to prevent the convection from taking place inside the pond's body and, as a result, the heat loss from the lower zone to the upper zone may occur by conduction but not convection. By this manner, the middle acts as insulator layer to reduce the lower zone upward heat loss significantly.

### **2.2.1.2 Membrane stratified solar Ponds**

Membrane stratified solar pond is a type of non salt solar ponds, which is a body of liquid utilizing closely spaced transparent membranes. Membrane ponds utilize the same concept as solar gradient solar ponds, except for the fact that a thin transparent membrane is fixed to separate each zone of the pond. The membrane space for

suppressing convection, should be very small and a large number of high transparent films are required [33]. The buoyancy effect is balanced by the weight of water so that solar radiation is converted into sensible heat [34]. Three types of membranes are suggested for the membrane stratified solar pond, which are [35] horizontal sheets, vertical tubes, and vertical sheets.

### **2.2.1.3 Viscosity stabilized solar pond (VSSP)**

Nonconvective layers of solar ponds are ordinarily composed of salt gradient layers. Salt gradient solar ponds, however, have a number of difficulties, they may cause environmental pollution in the event of a salt leakage and the salt gradient layer needs frequent maintenance. In order to eliminate these problems, Shaffer [36] proposed a new type of solar ponds using a transparent polymer gel as a nonconvecting layer. The polymer gel has low thermal conductivity and is used at a near solid state; so that it will not convect [33]. Materials suitable for viscosity stabilized solar ponds should have high transmittance for solar radiation, high efficiency of the chosen thickness and should be capable of performing at temperatures up to 60 °C. Polymers such as gum Arabic, Locust bean gum, Starch and Gelatin are all potentially useful materials. The ideas of viscosity stabilized solar pond appears to be promising but presently is not economically competitive salt gradient solar pond [32]

## **2.2.2 Convecting Solar Ponds**

A convecting solar pond is usually a horizontal solar collector that normally consists of one homogenous liquid layer with a transparent cover on the pond's surface. This transparent cover reduces heat loss by impeding evaporation and convection conduction. The cover can also prevent external effects such as wind shear, dust, falling impurities, etc. Convecting solar ponds have classified in varying ways, for example, Kreider and Kreith categorized these ponds according to depth, differentiating between shallow and deep saltless solar ponds [9]. Other researchers consider all convecting solar ponds to be shallow solar ponds and, therefore, have classified these ponds on the basis of operational modes, relating to batch and continuous shallow pond systems [37].

### **2.2.2.1 Shallow Solar Pond (SSP)**

The shallow solar pond is a large solar energy collector that consists of a plastic envelope containing water [38]. As the name of convective shallow pond suggests, the depth of water is relatively small ,usually between 4 and 15cm [39], and the layer is homogeneous.

The concept underpinning the SSP has been known since the beginning of the twentieth century, when Willsie and Boyle [40] used the idea to produce shaft power. They tried various designs of solar pond and one of these was composed of a wooden tank lined with tar paper and covered with a double glass window, while each side and bottom were insulated with hay. The water level in the tank was 7.5cm. Other

designs included asphalt and sand for insulation, however, the latter could not be kept dry, so the heat loss from the base was high. In 1906 and 1908, Willsie and Boyle succeeded in raising the temperature from 38 to 80°C by using dual stages, and single and double glass covers (of 110m<sup>2</sup>); 11kW of peak power was obtained. Also in the beginning of the twentieth century, Shuman [41] ran a steam engine on the same system used by Willsie and Boyle. Furthermore, shallow ponds were used in Japan for domestic purposes in the 1930s [42].

After about half a century, the shallow pond technique was suggested to produce power by D'Amelio [43], and research to develop SSPs was adopted by The Office of Saline Water, US Department of Interior [44].

More recently, a research team at the University of Arizona developed an SSP to be combined with a multiple-effect solar still for the purpose of desalination. This system produced 19m<sup>3</sup>/day of distilled water using 5 ponds (each about 90m x 2m) [45].

A group of researchers at Texas A&M University [46] tried to improve the SSP by using a completely black butyl rubber bag. However, the result was exactly the opposite of what they had tried to achieve: the temperature of the top surface of the bag was 30°C hotter than the water directly underneath. So, the conclusion confirmed that the upper cover should be a transparent film.

Around 1975, the Lawrence Livermore Laboratory in California, USA [37] and the Solar Energy Laboratory at the Institute for Desert Research in Israel [47] were established and teams were formed for solar energy research. The former research centre constructed several large-scale SSP projects in different designs [9] and soon after, many significant results were obtained and published by W. Dickinson and other researchers [37]. In the latter centre, the SSP was involved in a large-scale project of solar energy and good experiment results were delivered. After that, Kudish and Wolf [48] designed a portable shallow pond for camping and military use. During the past 30 years, SSPs have been used in many countries, such as Iran [49] and Egypt [50].

A typical SSP consists of a low-depth volume of water enclosed in 60m x 3.5m (approximately) plastic bag, with a blackened bottom and colourless top film. This bag is insulated below with foam insulation and on the top with single or double glazed panel, as shown in Figure 2.4 [9]. The shallow solar pond can be operated in batch or continuous modes. In batch operation, the water is insulated during daytime. Before nightfall, it is pumped into a large insulated tank for night storage and then pumped back into the bag after sunrise every day. If the water flows continuously through the water bag, this operational method is then called the flow-through mode, which is also named by some researchers [9] as deep saltless solar pond [51].

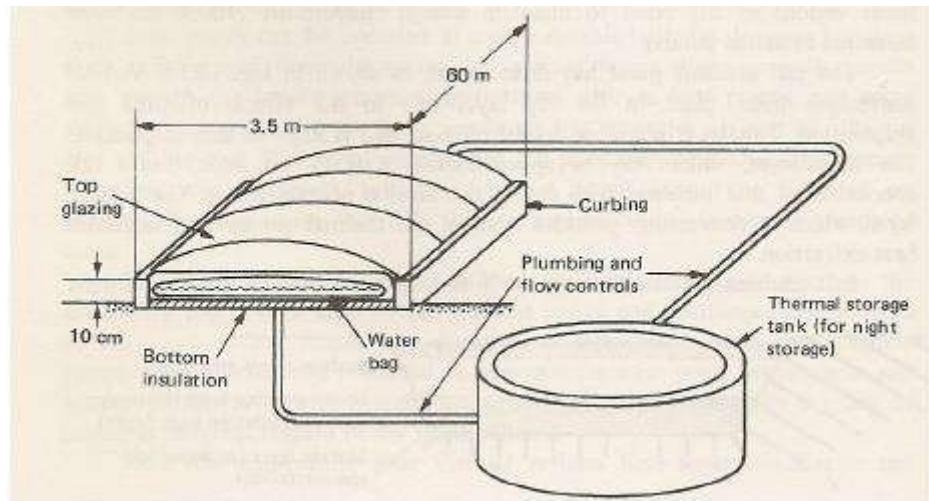


Figure 2.4: A typical shallow solar pond[52].

### 2.2.3 Partitioned solar pond (PSP)

Tabor [53] has reported the following problems that occurred during the operation of solar pond: (i) biological growth of algae and bacteria, (ii) dirt falling into the pond and decreasing its transparency. (iii) Evaporation causing too high concentration at the top and (iv) disturbance of the concentration gradient while extracting heat. Adding chemicals can prevent biological growth [54]. The other problems may be overcome by installing two transparent partitions one on top or few centimeters below the surface of the pond and the other at a depth of 1–2 m. A thin water layer above the top partition brings both advantages and disadvantages. The disadvantages, especially in windy locations, include evaporative cooling and increased reflectivity due to wave action. On the positive side, there is a decrease in reflective losses because the water has a lower index of refraction than plastics, so that reflective losses at a water-plastics boundary are small. The lower partition separates the insulating layer from the convective layer. It improves the stability of the pond and facilitates the extraction of heat. Instabilities due to buoyancy can be avoided either by making the lower partition stiff (e.g. glass panes) or if a flexible partition (e.g., a Tedlar sheet) is used, by filling the convection zone with salt water. To improve convection, heat is extracted just below the partition either by removing hot water or brine directly or by running fresh water through a network of heat exchanging plastic pipes. The Tedlar may be preferable if brine is used in the convective zone [54].

### 2.2.4 Saturated solar pond (STSP)

The problems of maintenance density in the conventional salt gradient solar pond (CSGSP) can be overcome by making the pond saturated at all levels, with a salt whose solubility increases with temperature. Such saturated ponds have no apparent diffusion problems and the gradients are self-sustaining depending on local temperature; thus the main advantage of such a pond is its inherent stability. In such a pond, vertical diffusion of salt is prevented and the density gradient is stable; thus making the pond maintenance free [55]. Salt gradient solar ponds have advantages for long-term energy storage. In contrast, nonsalt solar ponds such as membrane stratified

ponds and shallow solar ponds, are more suitable for short-term energy storage because the temperature rise of the pond water is rapid. The performance of these nonsalt solar ponds was established by field tests, and reference data for design of these solar ponds were obtained from the results of the experiments and analysis [56].

### **2.3 Construction of a solar pond**

Construction of a solar pond is very easy. At the base of the pond, the calculated amount of salt is mixed with fresh water until the pond is half full. In order to maintain salinity gradient, brine was injected into the LCZ and fresh water is supplied through the UCZ. Jaefarzadeh [57] studied various methods of salt injection in the LCZ. A salt gradient solar pond coupled with evaporation pond was studied by Agha et al. [58,59]. They proved that salt reconcentration by evaporation was an effective method of providing salt to the main solar ponds. Similar model was presented by Ouni et al. [60] and Alagao [61]. They proved that the efficiency of the solar pond was 10–30%, if the storage zone temperature is 40–80 °C.

#### **2.3.1 Size**

In the last 20 years, many salt gradient solar ponds varying in size from a few hundred to a few thousand square meters [62] of surface area have been built in a number of countries. A truncated conical shaped, portable mini solar pond, with cross-sectional area of 1m<sup>2</sup> was designed by Tahat et al. [63] to study thermal behavior. They attained a maximum temperature of 100 1C, when the depth of NCZ is 300 mm. Aboul-Enein et al. [64] designed a rectangular-shaped mini solar pond of area 1m<sup>2</sup>. Mirror and baffle plates [65] are also used to increase the performance of the pond. Taga et al. [66] used transparent double film at the roof of the solar pond. Tiwari et al. [67] studied the effect on thermal trap on the performance of an underground shallow solar pond water heater.

#### **2.3.2 Salt used**

Normally sodium chloride salt is used in the solar pond. Hassairi et al. [68] used natural brine. But the maximum temperature obtained in the natural brine solar pond is less than sodium chloride used solar pond. Murthy and Pandey [69] used fertilizer salts for operating solar ponds.

### **2.4 Applications of solar ponds**

Because of large storage of heat and negligible diurnal fluctuation in pond temperature, solar pond has variety of applications like, heating and cooling of buildings, swimming pool and greenhouse heating, industrial process heat, desalination, power production, agricultural crop drying, etc.

### **2.5 Factors affecting performance of solar ponds**

The thermal efficiency of the pond depends on the thickness of the various zones in

the solar pond. An increase in thickness of the UCZ reduces the amount of solar energy reaching the storage zone. Therefore the thickness of the UCZ should be very less. The various factors, affecting thermal performance of the solar pond are discussed under. Xiang et al. [70] did the thermal calculation by changing the incident rays from a Xe-lamp into natural ray and halogen lamp. As a result, it was found that the temperature distributions in the solar pond were notably different due to spectral characteristics of the incident ray. Therefore, the spectroscopic consideration for thermal performance of any solar pond was necessary to obtain a correct solution under the spectral incidence with special wavelength distribution.

### **2.5.1 Water turbidity and bottom reflectivity**

The suspended matter in solar pond salt water, which prevents the penetration of light inside water, is called turbidity. Jackson turbid meter is used to measure turbidity. The unit for turbidity is helometric turbidity units. Wang and Yagoobi [71] studied the effect of turbidity on the thermal performance of a salt gradient solar pond. They found that high turbidity levels could prevent ponds from storing energy in the LCZ. Husain et al. [72] proved that reflective bottom and turbidity with certain limits improve the efficiency of pond. Giestas et al. [73] studied the gravitational stability of a salty layer of a fluid subject to an adverse temperature gradient as a result of heat absorption.

### **2.5.2 Wall shading effect**

The thermal performance of a solar pond is a function of solar irradiation, heat losses from the sides to the surroundings and from the LCZ towards the upper layers, ultimate storage capacity, and the effectiveness of the heat exchanger system. In small vertical wall solar ponds, the shading of walls plays an important role on reducing the sunny area of the pond and its thermal performance. Jaefarzadeh [74] analyzed the effect of wall shading on the LCZ temperature. A numerical investigation was conducted by Jubran et al. [75]. They developed a model to predict the generation of convective layers on the solar pond walls.

### **2.5.3 Effect of energy extraction**

The temperature of the UCZ and LCZ are almost uniform. The temperature of the NCZ increases, when the depth increases. When the thickness of the NCZ increases, the temperature of the UCZ also increases. Al-Jamal and Khashan [76] proved that the thickness of the NCZ was dependent on the amount of heat extracted from solar pond.

## **2.6 Methods to improve performance of solar ponds**

To increase the temperature of the LCZ, Aboul-Enein et al. [64] used plane mirror at the top portion of the mini solar pond. To minimize the shadow effect, Ibrahim and El-Reidy [77] used mobile covered shallow salt less solar pond. Higher water temperature was obtained when the reflector is adjusted than the adjusting the orientation angle of the pond. A baffle plate was used and thermal performance was

studied by El-Sebaii [65] and proved that the performance of the pond with the baffle plate is better than that of the pond without the plate and the thermal conductivity of the baffle plate has no effect on the pond performance. A solar pond with honeycomb surface insulation system was designed by Arulanantham et al. [78] to minimize the losses. They also proved that efficiency of the pond is around two times greater than ordinary conventional salt gradient solar ponds. In solar ponds, the LCZ plays a dual role. Heat is extracted from solar pond from this zone only. Also it is acting as a storage zone. A method was suggested by Prasad and Rao [79] to estimate the thickness of the LCZ of the solar ponds. Rivera and Romero [80] used a single stage heat transformer operating with the water/lithium bromide mixture to demonstrate the feasibility of the systems to increase the temperature of the heat obtained from solar ponds.

## 2.7 Solar energy versus fossil fuel

### 2.7.1 Environmental

Fossil fuels are nonrenewable sources of energy, they have adverse impacts on the environment, and their supply is finite. Burning fossil fuels is the largest single source of pollution in the atmosphere. The combustion of fossil fuels produces air pollutants including sulfur dioxide, nitrogen oxides, hydrocarbon compounds, carbon monoxide and particulate matter. In the atmosphere, sulfur dioxide and nitrogen oxides are converted into sulfuric acid and nitric acid, the components of acid rain. Nitrogen oxides and volatile hydrocarbons react in sunlight to form ground level ozone, the principal component of urban smog [81].

Burning of fossil fuels is a major factor that contributes to the global climate change, which is resulting from the build-up of greenhouse gases (gases that trap heat in the atmosphere). Global climate change has created global concern for the entire world, since it exacerbates the floods, droughts, storms, diseases, and famines. For all these reasons, using renewable energy has become a global trend. In 1997, the Kyoto Protocol was agreed upon; it is the world's only international agreement with binding targets to reduce greenhouse gas emissions. As such, it is the primary tool with which governments of the world can address climate change; so far, 129 countries have ratified or acceded to the protocol [82].

On the other hand, solar energy is a renewable resource; it is abundant, inexhaustible, and free. Solar power has little adverse environmental impact, with none of the polluting emissions or safety concerns associated with conventional energy generation technologies.

There is hardly any pollution in the form of exhaust fumes or even noise during operation. Each square meter of the reflector surface in a solar field is enough to prevent the production of 150–250 kg/year of the greenhouse gas, carbon dioxide. Therefore, solar power can make a substantial contribution towards international commitments to reduce the steady increase in the level of greenhouse gases and their contribution to climate change [82].

Notwithstanding, it is worthwhile to mention that solar energy is intermittent. There is no radiation at night, and in winter and cloudy days the solar radiation intensity is low. This problem can be solved by supporting solar energy with fuel heaters or using storage heat medium.

### 2.7.2 Economy

Fossil fuel costs are expected to rise with growing scarcity. The fact that the Gaza Strip is poor in fossil fuel and relies on imported supplies already places a heavy financial burden on the people. In addition, the supply of fossil fuels to the region is highly affected by the political events in the Middle East; therefore there is no guarantee of steady supply and/or stable prices.

## 2.8 Solar Radiation Behavior in a Body of Water

When the incident solar radiation falls on a body of water, some of the sunlight is reflected back to the sky and the rest is absorbed by the surface of the water, the energy of which penetrate to over a hundred meters in depth.

### 2.8.1 Sunlight Reflection

The amount of reflected solar light towards the sky depends on the position of the sun ( $\theta$ ) and the condition of the water's surface. A rough surface tends to absorb more sunlight and a glass-like surface reflects more, however the roughness of the surface has little effect as long as a wind speed is less than 15.4m/s [83]. When the surface of water is not turbulent or is only slightly turbulent, the surface reflection can be calculated by Fresnel's equation [84]:

$$Fr(\theta) = \frac{1}{2} \left[ \frac{\sin^2(\theta - \theta_r)}{\sin^2(\theta + \theta_r)} + \frac{\tan^2(\theta - \theta_r)}{\tan^2(\theta + \theta_r)} \right] \quad (2.2)$$

where  $\theta$ = incident angle in degrees, and  $\theta_r$  = reflective angle in degrees.

The Fresnel reflection ( $F_r$ ) computes the ratio of the amount of reflected ray to the incident beam. Figure 2.5 illustrates that the reflected ray represents a small fraction, about 2-5%, most of the day and is only high when the sun is near to sunrise and sunset.

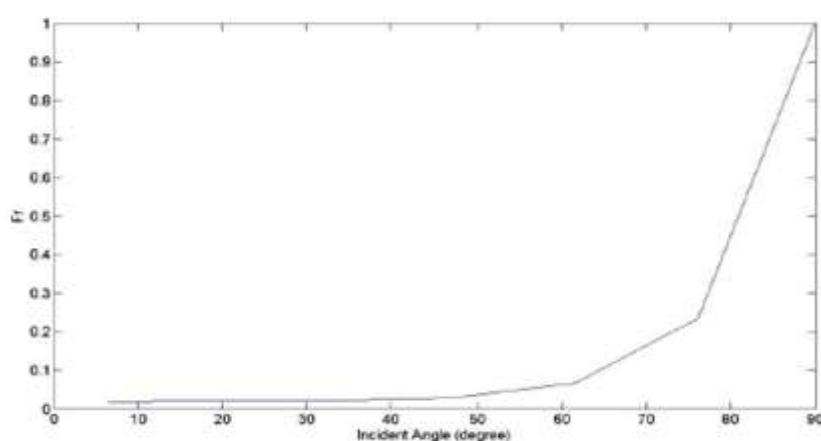


Figure 2.5 : Fresnel reflection ( $F_r$ ) with the incident angle( $\theta$ )

### **2.8.2 Sunlight Transmission**

The remaining part of the sunlight, after reflection, penetrates the air-water interface and is refracted into the water medium. This refraction of the incident solar radiation can be predicted by Snell's Law:

$$\frac{\sin \theta_r}{n} = \frac{\sin \theta}{n_r} \quad (2.3)$$

where n = air refractive index, and  $n_r$  = water refractive index.

The solar light travels deeper in the water for many meters depending upon the transparency and clearness of the water. Water impurities may scatter and/or absorb the beam and vice versa; clear water allows it to travel further, and therefore the water should be maintained as clear as possible.

### **2.8.3 Sunlight Absorption**

The propagated light within a medium of water is attenuated by absorption and scattering. The latter is caused mainly by the presence of biological organisms and suspended particles [85], while water molecules themselves cause a minor effect in terms of scattering. It is a useful simplification to consider that the scattering direction is in a forward direction.

## **2.9 Solar Radiation Variability - Recent Decades**

Solar radiation is the full frequency spectrum of the electromagnetic radiation that reaches the Earth's surface from the Sun; this is usually experienced as daylight. Solar radiation can be filtered by the atmosphere, particularly by clouds, and in some parts of the world, climate change has resulted in increased levels of cloud cover, resulting in reduced levels of solar radiation.

There are two key variables in terms of resultant/usable solar radiation: latitudinal location and angle of incidence (governed by the seasons); however, there is a further consideration, that of the Sun's 11-year cycle. Solar radiation levels can be measured by satellite, i.e. before the effects of any filtering have taken place, but solar radiation measured on the Earth's surface is called global horizontal radiation (sometimes, simply 'total solar radiation'), which consists of two parts; direct and diffused solar radiation. Direct radiation has not been the focus of much study, and thus there is little understanding of the long-term behaviour of direct radiation [86]. Nevertheless, studies have been conducted into the long-term behaviour of total solar radiation, and these are generally agreed that over recent decades, variability has been in evidence.

## **2.10 Reject water (brine) management**

Until the early 1960s, the use of desalination processes was very limited in the water industry. Their applications were restricted to activities where almost distilled water was required. Since then, many plants have been erected in various parts of the world for supplying water for various purposes. Based on the process, desalination plants

can be categorized into two types. The first involves plants that employ a phase-change process. In such plants desalination takes place while there is a change of phase (i.e., evaporation or freezing). Plants that follow such a process include multi-stage flash (MSF), multi-effect boiling (MEB), vapor compression (VC), solar distillation, and freezing. The second type of desalination plants are single phase. In such plants the extraction of salt takes place while the solution remains in the liquid phase. These include reverse osmosis (RO) and electrodialysis (ED).

One common aspect to both categories of desalination plants is the production of concentrate. The amount of concentrate as a percentage of the feed water varies depending on the choice of method, initial salinity of feed water, and factors affecting the choice of disposal method.

Awerbuch and Weekes [87] reported that brackish RO plants, in general, produced 25% of the total feed water flow as reject brine. They described the use of evaporative brine concentrators to reduce the RO reject brine to 2% of the overall flow. According to Alaabula'aly and Al-Saati [88], groundwater RO plants typically produce a brine stream of 10-25% of the feed. Thermal processes such as MSF and MEB have relatively low water recoveries. The concentrate from thermal processes is typically mixed with cold water prior to discharge. The dilution of concentrate results in a final discharged effluent that is rarely more than 15% higher in salinity than the receiving water [89]. Other wastes produced by desalination plants (e.g., cleaning wastes) are either mixed with the concentrate or stored separately to be disposed of later.

## 2.11 Chemistry of concentrate

The characteristics of reject brine (concentrate) are directly related to the quality of the feed water, the desalination technology used, the percent recovery, and the chemical additives used. Khordagui [90] presented the chemical properties of reject brine from some Gulf region desalination plants (Table 2.2). Mickley et al. [89] classified wastes generated by the different components of the membrane desalination process into the following categories: pretreatment waste, membrane concentrate, cleaning waste, and post-treatment waste.

Table 2.2 : Characteristic of reject brine water from some desalination plants in the Gulf region (after Khordagui [90])

Parameters	Abu-fintas Doha/Qater seawater	BWRO Ajman	BWRO Um Quwain	Qidfa I Fujairah seawater	Qidfa II Fujairah seawater
Temperature, °C	40-44	30.6	32.4	32.2	29.1
pH	8.2	7.46	6.7	6.97	7.99
Electrical conductivity	NR	16,49	11,33	77.0	79.6
Ca, ppm	1300-1400	312	173	631	631
Mg, ppm	7600-7700	413	282	2,025	2,096
Na, ppm	NR	2,756	2,315	17,294	18,293
HCO <sub>3</sub> , ppm	3900	561	570	159	149.5
SO <sub>4</sub> , ppm	3900	1,500	2,175	4,200	4,800
Cl, ppm	29,000	4,572	2,762	30,487	31,905
TDS, ppm	52,000	10,114	8,276	54,795	57,935
Total hardness, ppm	NR	NR	32	198	207
Free Cl <sub>2</sub> , ppm	Trace	NR	0.01	NR	NR
SiO <sub>2</sub> , ppm	NR	23.7	145	1.02	17.6
Langlier SI	NR	0.61	0.33	NR	NR
Cu, ppb	<20	NR	NR	NR	NR
Fe, ppb	<20	NR	NR	NR	NR
Ni, ppb	Trace	NR	NR	NR	NR
Antiscale, ppm	0.8-1.0	NR	NR	NR	NR
Antifoam, ppm	0.04-0.05	NR	NR	NR	NR

NR, not reported.

In RO systems, especially in plants that produce drinking water, pretreatment may consist of acidification, addition of anti-scalant chemicals, chlorination, and de-chlorination. For poor quality water, filtration, coagulation, flocculation, ion exchange, and carbon adsorption may also be used. All these processes generate wastes that are removed before the membrane process starts. Membrane concentrate is primarily a concentrate of the feed water that includes the raw water along with the added chemicals for pretreatment purposes. If post-treatment is done on the concentrate, its characteristics are further affected.

Chemical concentrations in the concentrate depend on the membrane system recovery and the membrane rejection of a particular chemical. The concentrate from membrane desalination processes is characterized by high total dissolved solids (TDS) and has minimal amounts of process-added chemicals. In general, raw water quality determines the final concentrate quality. The degree of concentration, also called the concentration factor (CF), is defined as:

$$CF = \frac{1}{1-R} \quad (2.4)$$

where R is the fractional recovery. The above relationship is valid for chemicals that are completely rejected by the membrane but is a good approximation for most chemicals in brackish and seawater RO systems.

## 2.12 Brine disposal methods

Reviewing the characteristics of brine disposal from desalination plants, Koenig [91] noted that brine disposal is in a different category than sewage disposal. He also stated that there is no way to reduce brine to simpler and harmless compounds as they are already the simplest of inorganic compounds. He went on to say that no good way exists to reclaim the carrying water from the dissolved solids, for if there were, it could be used in the desalting process. While the quantities of materials are very large, Koenig [91] emphasized that these materials do not look attractive economically.

Guidelines issued by the US Federal Water Pollution Control Administration [92] for disposal systems in the USA emphasize that such systems must comply with federal, state, and local regulations; avoid pollution, lawsuits, and be in good engineering practice; be capable of adequately taking care of all the effluents continuously over the life of the plant; not unduly harm the land, surface, and underground fresh water sources, sheltered bays and estuaries, or the seas; and not contaminate the feed water intake or future resources. In the Gulf countries most of the large-scale desalination plants are located on the coastline. These plants discharge their concentrate into near shores. Khordagui [90] and the SWCC [93] looked into this issue in a comprehensive manner. Desalination industry experts have accepted the fact that the ocean brine disposal method is the least expensive method. They argue that rapid mixing and dilution makes it a "safe" disposal option. Mandil [94] observed that the environmental impact of brine discharge is related to the physical, chemical, and biological characteristics of the receiving marine environment. The recovery ratio, or the amount of feed water that must be provided to the plants for each unit of product water, has

significant environmental implications. The higher the recovery ratio, the greater the salinity of the concentrate.

Khordagui [90] supported the practice of ocean brine disposal with the argument that the amount of seawater withdrawn for desalination is relatively minute when compared to the water mass of the open sea. He stated that the amount and nature of salts discharged with the brine are identical to the salt content of the open sea, with the concentration factor increasing by no more than two. In order to avoid recirculation of plant effluents to the intakes of the desalination plants, Khordagui [90] emphasized that the outlets should be specifically engineered to discharge in coastal areas where maximum circulation patterns and hydrographic currents can easily disperse and dilute the brine. On the other hand, Del Bene et al. [95] concluded that dense brine discharge into the ocean can impact the benthic environment.

Table 2.3: summarizes the advantages and disadvantages of the most common brine disposal methods in the wider context of environmental protection focussed on the associated impacts and cost (Ahmed et al., [96]), (Khordagui, [97]), (Mickley, [98]), (Jirka, 99), (Del Bene et al., [100]), (Truesdall et al., [101]).

<b>Disposal method</b>	<b>Advantages</b>	<b>Disadvantages</b>
<i>Direct surface water discharge</i>	<ul style="list-style-type: none"> <li>• <i>Natural processes promote degradation.</i></li> <li>• <i>Can accommodate large volumes .</i></li> <li>• <i>Water body promotes dilution.</i></li> <li>• <i>Low cost .</i></li> <li>• <i>High dilution rates in the water body , possible dilution and blending with power plant discharge .</i></li> </ul>	<ul style="list-style-type: none"> <li>♦ <i>Dilution depends on local hydrodynamic conditions.</i></li> <li>♦ <i>Good knowledge , monitoring and planning programs of receiving waters are required .</i></li> <li>♦ <i>Limited natural assimilation capacities cause adverse impacts on marine environment if exceeded.</i></li> <li>♦ <i>Thermal pollution , reduction of dissolved oxygen in receiving waters eutrophication , toxicity , PH increase , damage of biota.</i></li> </ul>
<i>Discharge to a sewage treatment plant</i>	<ul style="list-style-type: none"> <li>• <i>Lowers the BOD of the resulting effluent .</i></li> <li>• <i>Dilutes the brine concentrate</i></li> <li>• <i>Uses existing infrastructure .</i></li> </ul>	<ul style="list-style-type: none"> <li>♦ <i>Can inhibit bacterial growth .</i></li> <li>♦ <i>Can hamper the use of the treated sewage for irrigation due to the increase in TDS and salinity of the effluent .</i></li> <li>♦ <i>Overload the existing capacity of the sewage treatment plant while diminish its usable hydraulic capacity .</i></li> </ul>
<i>Deep well injection</i>	<ul style="list-style-type: none"> <li>• <i>Viable for inland plants with small volumes of brine .</i></li> <li>• <i>No marine impact expected.</i></li> </ul>	<ul style="list-style-type: none"> <li>♦ <i>Cost efficient only for larger volumes .</i></li> <li>♦ <i>Needs a structurally isolated aquifer.</i></li> <li>♦ <i>Increases the salinity of groundwater.</i></li> </ul>
<i>Land applications</i>	<ul style="list-style-type: none"> <li>• <i>Can be used to irrigate salt tolerant species.</i></li> <li>• <i>Viable for inland plants with small volumes of brine .</i></li> <li>• <i>No marine impact expected.</i></li> </ul>	<ul style="list-style-type: none"> <li>♦ <i>Requires large areas of land .</i></li> <li>♦ <i>Suitable for smaller discharge flows</i></li> <li>♦ <i>Can affect the existing vegetation .</i></li> <li>♦ <i>Can increase the salinity of groundwater</i></li> </ul>

		<i>and underlying soil .</i> ♦ Storage and distribution system needed.
<i>Evaporation ponds</i>	<ul style="list-style-type: none"> <li>● <i>A viable option for inland plants in highly arid regions .</i></li> <li>● <i>Possible commercial salt exploitation.</i></li> <li>● <i>No marine impact expected.</i></li> </ul>	♦ <i>Expensive option .</i> ♦ <i>Risk of underlying soil and groundwater pollution.</i> ♦ <i>Needs dry climates with high evaporation rates .</i> ♦ <i>Requires large areas of land with a level terrain .</i> ♦ <i>Needs regular monitoring .</i>
<i>Brine concentrators/zero liquid Discharge</i>	<ul style="list-style-type: none"> <li>● <i>Low technological and managing efforts .</i></li> <li>● <i>Can produce zero liquid discharge .</i></li> <li>● <i>Can commercially exploit concentrate .</i></li> <li>● <i>Recovery of salt and minerals .</i></li> <li>● <i>No marine impact expected.</i></li> </ul>	♦ <i>Expensive.</i> ♦ <i>High energy consumption.</i> ♦ <i>Production of dry solid waste- precipitates.</i>
<i>Mixing with the cooling water discharge</i>	<ul style="list-style-type: none"> <li>● <i>Achieve dilution of both effluents prior to discharge .</i></li> <li>● <i>Combined outfall reduces the cost and environmental impacts of building two outfalls .</i></li> <li>● <i>Necessary to reduce salinity if disposing in fresh water bodies .</i></li> </ul>	♦ <i>Dependent on the presence of a nearby thermal power plant.</i>
<i>Mixing with the sewage treatment effluent</i>	<ul style="list-style-type: none"> <li>● <i>Achieve dilution of brine effluent prior to discharge .</i></li> <li>● <i>Does not overload the operational capacity of sewage treatment plant.</i></li> <li>● <i>Use of existing infrastructure .</i></li> <li>● <i>Necessary to reduce salinity if disposing in fresh water bodies.</i></li> </ul>	♦ <i>The brine could enhance the aggregation and sedimentation of sewage particulates that can impact benthic organisms and interfere with the passage of light in the receiving water body.</i>

Source : Adopted from "Report on the evaluation of existing methods on brine treatment and disposal practices" in Development of an advanced, innovative, energy autonomous system for the treatment of brine from seawater desalination plants by SOL-BRINE on June, 2012.

## Chapter 3: Theoretical background

### 3.1 Salt-making from brine

Solar evaporation of brine to form salt continues to be a viable commercial process to this day along coastal areas [102]. The procedures used in making salt varied by geographic region and resources locally available. The quantity desired by the local population may have also influenced the choice of salt production methods.

Although the process often involved techniques such as leaching, extraction, filtering, and burning of salt-enriched plants [103], the final step in salt production invariably required evaporation of water from brine to precipitate salt crystals.

For any batch evaporation the amount of salt produced can be determined by

$$m_s = m_w(1.52 \times 10^{-4} S^2 + 9.50 \times 10^{-3} S) \quad (3.1)$$

Where

$m_s$  = the mass (kg) of salt crystallized,

$m_w$  = the mass (kg) of the water evaporated,

$S$  = the initial salt concentration of the brine in wt% NaCl (Fig.3.1).

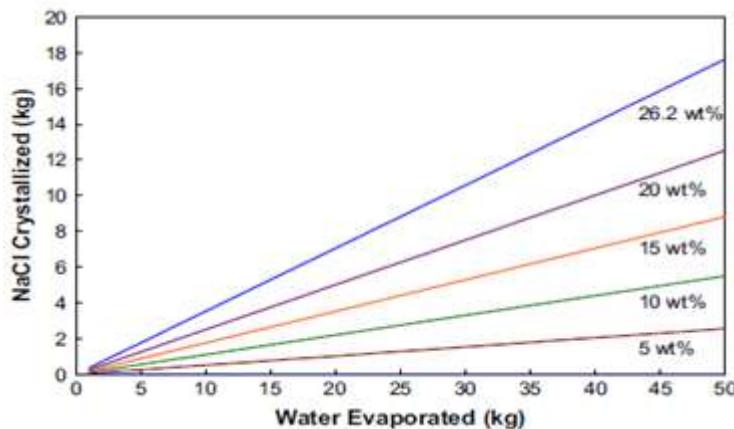


Figure 3.1 : Graphical representation of Eq. (3.1). The maximum sodium chloride brine concentration is 26.2 wt % (at 25°C). For comparison, seawater has a salt content of about 3.5 w t%.

To calculate wt% NaCl :

In chemistry, the mass fraction  $w_i$  is the ratio of one substance with mass  $m_i$  to the mass of the total mixture  $m_{tot}$ , defined as [104]:

$$w_i = \frac{m_i}{m_{tot}} \quad (3.2)$$

The sum of all the mass fractions is equal to 1:

$$\sum_{i=1}^N m_i = m_{tot}; \sum_{i=1}^N w_i = 1 \quad (3.3)$$

Mass fraction can also be expressed, with a denominator of 100, as percentage by mass (frequently, though erroneously, called percentage by weight, abbreviated wt%).

For ease of calculation, the dissolved salt is assumed to be pure sodium chloride. Sodium and chlorine make up 85% of the inorganic constituents found in seawater [105] and natural inland brines are often of even higher purity [106]. Consequently, the presence of other minor components has little impact on the numerically simulated results.

### 3.2 Solar evaporation

In solar evaporation a vessel or ponded area containing brine is allowed to evaporate under the prevailing environmental conditions. This technique works best at low latitudes where sunlight duration and intensity are highest and areas with low relative humidity and rainfall. Solar evaporation also becomes the default method when fuel resources are scarce and boiling of brine is unfeasible. Historically this technique was common in coastal areas [107] and continues to be a viable commercial process worldwide [102]. Solar evaporation could have been practiced at many inland salines where brine concentrations tend to be high [108] thus reducing total evaporation time.

#### 3.2.1 Calculation method for solar evaporation

Calculating evaporation rates for brine solutions requires a slight modification to the standard Penman (1948)[109] equation used by hydrologists to determine evaporation from open water sources. The Penman approach combines the effects of radiation and aerodynamic forces controlling evaporation and has been shown to adequately predict evaporation in a wide variety of environments [110]. The Penman equation is generally expressed as:

$$\lambda E = \frac{\Delta}{\Delta + \gamma} R_n + \frac{\gamma}{\Delta + \gamma} f(u)(e_s - e) \quad (3.4)$$

*Note: for calculation results see appendix F.*

Where

$E$  = the evaporation rate expressed as mm/day,

$\lambda$  = the latent heat of vaporization ( $\text{MJ Kg}^{-1}$ ),

$\Delta$  = the gradient of the vapor pressure-temperature curve,

$\gamma$  = the psychometric constant,

$R_n$  = the net solar radiation,

$f(u)$  = a function of wind speed,

$e_s$  and  $e$  are the saturation vapor pressure of water and ambient water vapor pressure, respectively.

##### 3.2.1.1 Calculating aerodynamic terms

The aerodynamic forces acting on evaporation are primarily the result of environmental variables governing diffusion of water molecules away from the liquid surface of water or brine. The modified Penman equation for predicting potential evaporation rates from a free water surface requires knowledge of several local

climate variables. The method shown here is for daily calculation steps and uses 24 h averages for temperature, humidity, and wind speed. For modeling past salt-making endeavors, historical weather data including average climate conditions for each month can be obtained for a variety of locales from several sources, including the Palestinian Meteorological Data in the Gaza Strip.

### 3.2.1.1.1 The latent heat of evaporation

The latent heat of evaporation also known as The enthalpy of vaporization or heat of evaporation, is the enthalpy change required to transform a given quantity of a substance from a liquid into a gas at a given pressure (often atmospheric pressure, as in STP).

STP Standard temperature and pressure (informally abbreviated as STP) as a temperature of 273.15 K (0 °C, 32 °F) and an absolute pressure of exactly 100 kPa (1 bar, 14.5 psi, 0.9869 atm)

The latent heat of evaporation  $\lambda$  (MJ Kg<sup>-1</sup>) varies with temperature according to

$$\lambda = 2.501 - 0.002361 T \quad (3.5)$$

*Note: for calculation results see appendix A.*  
where T is in degrees Celsius.

Where only (average) mean daily temperatures are available, the calculations can still be executed but some underestimation of ETo will probably occur due to the non-linearity of the saturation vapor pressure - temperature relationship [111].

The term evapotranspiration (ETo) is commonly used to describe two processes of water loss from land surface to atmosphere, evaporation and transpiration.

The temperature T for daily time steps is simply defined as the mean of the daily maximum and minimum temperatures.

$$T = \frac{T_{max} + T_{min}}{2} \quad (3.6)$$

Where

T = T<sub>mean</sub> = mean daily air temperature, °C;

T<sub>max</sub> = maximum daily air temperature, °C;

T<sub>min</sub> = minimum daily air temperature, °C.

### 3.2.1.1.2 The saturation vapor pressure $e_s$ (kPa)

The mean saturation vapor pressure e<sub>s</sub> (kPa) is determined from the average daily temperature and is an indication of the rate at which water molecules can escape from the liquid surface. When dissolved salts are present the saturation vapor pressure is lowered due to the decreased chemical potential of the liquid water. To adjust for this lowering effect the water activity coefficient  $a_w$  is inserted into the basic equation.

$$e_T = 0.6108 a_w \exp \frac{17.27 T}{237.3 + T} \quad (3.7)$$

Where;

$e_T$  = saturation vapor pressure at the air temperature T, kPa.

T = air temperature, °C.

$a_w$  = water activity coefficient.

Therefore, the mean saturation vapor pressure is calculated as the mean between the saturation vapor pressure at both the daily maximum and minimum air temperatures.

$$e_{(T_{\max})} = 0.6108 a_w \exp \frac{17.27 T_{\max}}{237.3 + T_{\max}} \quad (3.8)$$

$$e_{(T_{\min})} = 0.6108 a_w \exp \frac{17.27 T_{\min}}{237.3 + T_{\min}} \quad (3.9)$$

The mean saturation vapor pressure for a day should be computed as the mean between the saturation vapor pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e_{(T_{\max})} + e_{(T_{\min})}}{2} \quad (3.10)$$

*Note: for calculation results see appendix A.*

### 3.2.1.1.3 The activity coefficient of water $a_w$

The activity coefficient of water  $a_w$  is a function of the concentration of dissolved salts. The following correlation was derived from experimental vapor pressure data published for sodium chloride [105].

$$a_w = -0.0011m^2 - 0.0319m + 1 \quad (3.11)$$

*Note: for calculation results see appendix A.*

where

m = the concentration of sodium chloride in moles per liter of water.

### 3.2.1.1.4 The saturation vapor $\Delta$

The saturation vapor pressure is a function of temperature and the gradient of this function ( $\text{kPa}^{\circ}\text{C}^{-1}$ ) is also required and can be calculated by

$$\Delta = \frac{4098e_s}{(237.3 + T)^2} \quad (3.12)$$

*Note: for calculation results see appendix A.*

Where:

T =  $T_{\text{mean}}$  = mean daily air temperature, °C, [Eq.3.6].

$e_s$  = mean saturation vapor pressure, [Eq.3.10].

$\exp = 2.7183$  (base of natural logarithm).

### 3.2.1.1.5 Atmospheric Pressure (P)

The atmospheric pressure, P, is the pressure exerted by the weight of the earth's atmosphere. Evaporation at high altitudes is promoted due to low atmospheric

pressure. This effect is, however, small and in the calculation procedures, the average value for a location is sufficient. A simplification of the ideal gas law, assuming 20°C for a standard atmosphere, can be employed to calculate P in kPa at a particular elevation; If the atmospheric pressure is unknown, an approximate value can be calculated based upon a site's elevation as follow

$$P = 101.3 \left( \frac{293 - 0.0065z}{293} \right)^{5.26} \quad (3.13)$$

*Note: for calculation results see appendix A.*

where

$z$  = height above sea level (m).

$p$  = atmospheric pressure (kpa).

### 3.2.1.1.6 The psychrometric constant $\gamma$

The psychrometric constant relates the partial pressure of water in air to the air temperature so that vapor pressure can be estimated using paired dry and wet thermometer bulb temperature readings. Another way to describe the psychrometric constant is the ratio of specific heat of moist air at constant pressure ( $C_p$ ) to latent heat of vaporization. The specific heat at constant pressure is the amount of energy required to increase the temperature of a unit mass of air by one degree at constant pressure. Its value depends on the composition of the air, i.e., on its humidity. For average atmospheric conditions a  $c_p$  value of  $1.013 \times 10^{-3}$  MJ kg $^{-1}$  °C $^{-1}$  can be used. As an average atmospheric pressure is used for each location, the psychrometric constant is kept constant for each location depending of the altitude

The psychrometric constant (kPa°C $^{-1}$ ) is given by [112]:

$$\gamma = \frac{c_p p}{\varepsilon \lambda} = 0.000655P \quad (3.14)$$

*Note: for calculation results see appendix A.*

Where;

$\gamma$  = psychrometric constant, kPa °C $^{-1}$ ;

$P$  = atmospheric pressure, kPa, [Eq. 3.13];

$\lambda$  = latent heat of vaporization, 2.45, MJ kg $^{-1}$ ;

$c_p$  = specific heat at constant pressure,  $1.013 \times 10^{-3}$ , MJ kg $^{-1}$ °C $^{-1}$ .

$\varepsilon$  = ratio molecular weight of water vapour/dry air = 0.622.

### 3.2.1.1.7 Actual vapor pressure (e) derived from relative humidity

The actual vapor pressure can also be calculated from the relative humidity. Depending on the availability of the humidity data, different equations should be used.

The vapor pressure e (kPa) can be determined from the following formula

$$e = \frac{H_r e_s}{100} \quad (3.15)$$

where

$H_r$  = the relative humidity (%).

*Note: for calculation results see appendix B.*

In a similar fashion to the mean temperature, the daily mean vapor pressure is the average of the maximum and minimum values.

$$e = \frac{e_{\max} + e_{\min}}{2} \quad (3.16)$$

$$e = \frac{e_{(T_{\min})}[\frac{H_{r\max}}{100}] + e_{(T_{\max})}[\frac{H_{r\min}}{100}]}{2} \quad (3.17)$$

Where,

$e$  = actual vapour pressure, kPa;

$e_{(T_{\min})}$  = saturation vapour pressure at daily minimum temperature, kPa, [Eq. 3.9];

$e_{(T_{\max})}$  = saturation vapour pressure at daily maximum temperature, kPa, [Eq. 3.8];

$H_{r\max}$  = maximum relative humidity, %;

$H_{r\min}$  = minimum relative humidity, %.

### 3.2.1.1.8 Wind speed ( $U_2$ )

The average daily wind speed in meters per second ( $m s^{-1}$ ) measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ. The wind speed measured at heights other than 2 m can be adjusted according to the follow equation[112]:

$$u_2 = u_h \frac{4.87}{\ln(67.8h - 5.42)} \quad (3.18)$$

*Note: for calculation results see appendix B.*

Where,

$u_2$  = wind speed 2 m above the ground surface,  $m s^{-1}$ ;

$u_h$  = measured wind speed  $h$  m above the ground surface,  $m s^{-1}$ ;

$h$  = height of the measurement above the ground surface, m.

In case of wind speed is given in miles per hour ( $mi h^{-1}$ ) or (Km/h) the conversion to  $m s^{-1}$  is required.

$$u_2 (m/s) = u_2 (mi/h) * 0.477 \quad (3.19)$$

$$u_2 (m/s) = u_2 (Km/h) * 0.278 \quad (3.20)$$

Wind speed is incorporated using empirically determined coefficients for the atmospheric resistance encountered in diffusion of the water vapor away from a liquid surface. For an open water surface the wind function is given by

$$f(u) = 6.43(1+0.536 U_2) \quad (3.21)$$

*Note: for calculation results see appendix B.*

where the wind speed  $U_2$  ( $\text{m s}^{-1}$ ) is measured at 2 m above the surface.[Eq.3.18].

### 3.2.1.2 Determining net radiation

Solar radiation aids in promoting evaporation by imparting energy into the absorbing material. The radiational energy available at the ground surface is a combination of both short and long-wavelength radiation and is the difference between the upward and downward radiation fluxes. The amount of solar energy reaching the ground surface can be reduced by cloudiness and atmospheric interferences or increased with increasing altitude.

This net radiation,  $R_n$ , can be determined in three ways:

- (1) direct measurement using a radiometer,
- (2) published tables based on latitude, or
- (3) calculations incorporating Earth's orbital characteristics.

Radiometers measure the net radiation by monitoring the temperature difference across two parallel plates. They require periodic calibration and each measurement locale must be generally free of any obstructions blocking incoming or outgoing radiation. Approximate values for the net radiation reaching the ground surface can also be found in published tables [105]. These tables are generally organized by latitude and indicate the average net radiation for a cloudless sky during each month of the year. These tables do not usually account for altitude differences but are generally accurate to within 10% during summer months and 15% during winter months [105].

### 3.2.1.3 Calculating net radiation

Solar irradiation data have been widely measured and recorded for almost every region in each country of the world for many years. Nevertheless, predictions and calculations of irradiation are sometimes required to obtain a good approximation of incident radiation.

According to a solar pond's location, the sun's path in the sky changes seasonally, and thus the sun's altitude and azimuth angle as well as the daily sunshine period all vary; this has a great effect on the amount of incident solar radiation and then on the performance of the solar collector.

It is useful to define some common terms in solar radiation field:

**Irradiation:** The received solar energy per unit area on a surface.

**Direct Beam:** The direct received amount of solar energy without scattering by the atmosphere.

**Diffuse Beam:** The received solar energy after changing its direction due to scattering by the atmosphere.

**Total Solar Beam:** The sum of direct and diffuse beam on a surface.

**The Altitude (height) Angle ( $\alpha$ ):** This may be described as the angle between the centre of the sun's ray and a horizontal plane, as shown in Figure 3.2.

The solar altitude angle  $\alpha$  is the elevation of the sun, is the angle in a vertical plane between the sun's rays and the projection of the sun's rays on the horizontal plane.

It follows that  $\alpha + \theta = \frac{\pi}{2} = 90^\circ$ .

The approximate value for the solar altitude angle can be calculated with the following formula

$$\sin \alpha = \cos \theta = \sin \delta \sin \varphi + \cos \delta \cos \omega \cos \varphi \quad (3.22)$$

*Note: for calculation results see appendix C.*

Values north of the equator are (+) and those south are (-) values.

Where :

$\delta$  = The solar declination angle;

$\omega$  = The hour angle;

$\varphi$  = The latitude Angle.

$\theta$  = The solar zenith angle.

### ***The hour angle $\omega$ :***

The *hour angle*,  $\omega$ , is the azimuth angle of the sun's rays caused by the earth's rotation, and  $H$  can be computed from [113]

$$\omega = \frac{(\text{No of minutes past midnight,AST}) - 720 \text{ mins}}{4 \text{ min / deg}} \quad (3.23)$$

The hour angle as defined here is negative in the morning and positive in the afternoon ( $\omega = 0^\circ$  at noon). The hour angle expresses the time of day with respect to solar noon.

One hour of time is represented by  $\frac{360}{24} = 15$  degrees of hour angle. As part of the convention, the hour angle is negative before solar noon and positive after solar noon. It is positive during the morning, reduces to zero at solar noon and becomes increasingly negative as the afternoon progresses. Two equations can be used to calculate the hour angle when various angles are known (not that  $\delta$  changes from day to day and  $\alpha$  and  $Z$  change with time throughout the day):

$$\sin \omega = - \frac{\cos \alpha \sin Z}{\cos \delta} \quad (3.24)$$

$$\sin \omega = \frac{\sin \alpha - \sin \delta \sin \varphi}{\cos \delta \cos \varphi} \quad (3.25)$$

*Note: for calculation results see appendix C.*

Where:

$\omega$  = the hour angle;

$\alpha$  = the altitude angle;

$Z$  = the solar azimuth angle;

$\delta$  = the declination angle;

$\varphi$  = observer's latitude.

This equation is derived by substituting  $\alpha = 0$  into equation 3.22.

***The solar zenith angle ( $\theta$ )***: is the angle between the sun's rays and local vertical, i.e. a line perpendicular to the horizontal plane at P as shown in figure 3.2.

***The Solar Azimuth Angle (Z)***: is the angle in the horizontal plane measured clockwise from south to the horizontal projection of the sun's rays. The sign

convention used for the azimuth angle,  $Z$ , is negative east of south and positive west of south [114]. Notice that this sign convention results in the hour angle,  $\omega$ , and the sun's azimuth angle  $Z$ , always having the same sign. ( $-180^\circ \leq Z \leq +180^\circ$ ).

The mathematical expression for the solar azimuth angle is

$$\sin Z = \frac{\sin \omega \cos \delta}{\cos \alpha} = \frac{\sin \omega \cos \delta}{\sin \theta} \quad (3.26)$$

Note: The angle between zero and 180 degrees when the hour angle,  $\omega$ , is negative (morning) and the angle between 180 and 360 degrees when the hour angle,  $\omega$ , is positive (afternoon).

**Surface Azimuth Angle ( $\gamma$ ):** This is defined as the angles between the surface of the objective and the southern direction.

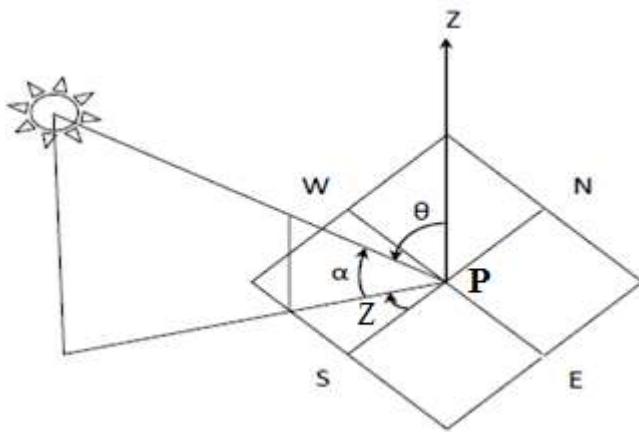


Figure 3.2 : Sketch explaining the Solar Altitude, Zenith and Azimuth Angles.

The following series of equations are required when determining the net radiation by accounting for Earth's orbital characteristics.

The Earth is divided into latitudes (horizontal divisions) and longitudes (N-S divisions). The equator is at a latitude of  $0^\circ$ ; the north and south poles are at  $+90^\circ$  and  $-90^\circ$ , respectively; the Tropic of Cancer and Tropic of Capricorn are located at  $+23.45^\circ$  and  $-23.45^\circ$ , respectively. For longitudes, the global community has defined  $0^\circ$  as the prime meridian which is located at Greenwich, England. The longitudes are described in terms of how many degrees they lie to the east or west of the prime meridian. A 24-hr day has 1440 mins, which when divided by  $360^\circ$ , means that it takes 4 mins to move each degree of longitude.

The apparent solar time,  $AST$  (or local solar time) in the western longitudes is calculated from

$$AST = LST + (4 \text{ min/ deg})(LSTM - Long) + ET \quad (3.27)$$

*Note: for calculation results see appendix B.*

where

$LST$  = Local standard time or clock time for that time zone (may need to adjust for daylight savings time,  $DST$ , that is  $LST = DST - 1 \text{ hr}$ ),

$Long$  = local longitude at the position of interest, and

*LSTM* = local longitude of standard time meridian

$$\text{LSTM} = 15^\circ * \left( \frac{\text{Long}}{15^\circ} \right) \text{round to integer} \quad (3.28)$$

*Note: for calculation results see appendix B.*

The difference between the true solar time and the mean solar time changes continuously day-to-day with an annual cycle. This quantity is known as the *equation of time*. The equation of time, *ET* in minutes, is approximated by [115]

$$\text{ET} = 9.87 \sin(2D) 7.53 \cos(D) 1.5 \sin(D) \quad (3.29)$$

$$\text{Where } D = 360^\circ \frac{(J-81)}{365} \quad (3.30)$$

*Note: for calculation results see appendix B.*

### 3.2.1.3.1 Mean daily solar radiation (*Rs*)

The average daily net radiation expressed in mega joules per square meter per day ( $\text{MJ m}^{-2}\text{day}^{-1}$ ) is required. A simple average of solar radiation values obtained from a weather station in the period of 24h (0:00:01 am to 11:59:59 pm) is required. The conversion of units is required when solar radiation is expressed in watts per square meter per day ( $\text{W m}^{-2} \text{ day}^{-1}$ ).

$$R_s_{(\text{MJ m}^{-2}\text{day}^{-1})} = R_s_{(\text{W m}^{-2}\text{day}^{-1})} * 0.0864 \quad (3.31)$$

### 3.2.1.3.2 The extraterrestrial radiation *R<sub>a</sub>*

The solar radiation at the entrance into the Earth atmosphere is known as extraterrestrial radiation. The intensity of extraterrestrial solar radiation is changeable because of the change in distance between the Earth and Sun and because of the Sun activity. The value of this radiation during the course of a year changes in the range from 1307 ( $\text{W/m}^2$ ) to 1393 ( $\text{W/m}^2$ ).

The extraterrestrial radiation *R<sub>a</sub>* ( $\text{MJ m}^{-2}\text{day}^{-1}$ ) can be calculated for any latitude and day of year by adjusting the solar constant *G<sub>sc</sub>* for the solar declination

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \quad (3.32)$$

*Note: for calculation results see appendix C.*

Where

*R<sub>a</sub>* = extraterrestrial radiation,  $\text{MJ m}^{-2} \text{ day}^{-1}$ ;

*G<sub>sc</sub>* = 0.0820  $\text{MJ m}^{-2}\text{min}^{-1}$ ,

*d<sub>r</sub>* = the inverse relative Earth-Sun distance,[eq.3.33].

*ω<sub>s</sub>* = the sunset hour angle (rad),

*φ* = the latitude (rad),

*δ* = the solar declination (rad).

**Solar constant *G<sub>sc</sub>*:** is the total amount of solar energy from the sun per unit time [ $\text{W/m}^2$ ] received on a unit area of surface perpendicular to the direction of

propagation of the radiation at mean earth-sun distance outside the atmosphere. The World Radiation Center (WRC) has adopted a value of  $G_{sc} = 1367 \text{ W/m}^2$ , with an uncertainty of the order of 1%.

### 3.2.1.3.3 The inverse relative distance Earth-Sun $d_r$

The inverse relative Earth-Sun distance  $d_r$  is given by

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad (3.33)$$

*Note: for calculation results see appendix B.*

Where,

$J$  = number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

Note: to convert date (MM/DD/YYYY) to Julian in Microsoft Excel the following command can be used:

$$=((\text{MM}/\text{DD}/\text{YYYY})-\text{DATE}(\text{YEAR}((\text{MM}/\text{DD}/\text{YYYY}),1",1"))+1)$$

OR the value of  $J$  for any day of the month "D" can be determined easily with the aid of Table 3.1.

Month	$J$ for the day of the month , D	Month	$J$ for the day of the month , D
January	D	July	181+D
February	31+D	August	212+D
March	59+D	September	243+D
April	90+D	October	273+D
May	120+D	November	304+D
June	151+D	December	334+D

Table 3.1: Variation in "J" throughout the year for use in Equation 3.33, 3.34, 3.35.

### 3.2.1.3.4 The solar declination $\delta$

The sun's declination angle,  $\delta$ , is the angular distance of a sun's rays north (or south) of the equator. It is the angle between a line extending from the center of the sun to the center of the earth and the projection of this line upon the earth's equatorial plane. At the time of the winter solstice, the sun's rays are 23.45 degrees south of the earth's equator ( $\delta = -23.45^\circ$ ). At the time of the summer solstice, the sun's rays are 23.45 degrees north of the earth's equator ( $\delta = 23.45^\circ$ ). At the equinoxes, the sun's declination is zero.

The declination is positive when the sun's rays are north of the equator and negative when they are south of the equator.

$$-23.45^\circ \leq \delta \leq +23.45^\circ$$

The declination angle throughout the year can be well approximated by a sine function:

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \text{ [Radians]} \quad (3.34)$$

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + J)\right] \text{ [degrees]}$$

(3.35)

*Note: for calculation results see appendix C.*

where  $J$  is the day of the year. Figure 3.3: shows the change in the declination angle throughout a year. Because the period of the Earth's complete revolution around the Sun does not coincide exactly with the calendar year the declination varies slightly on the same day from year to year.

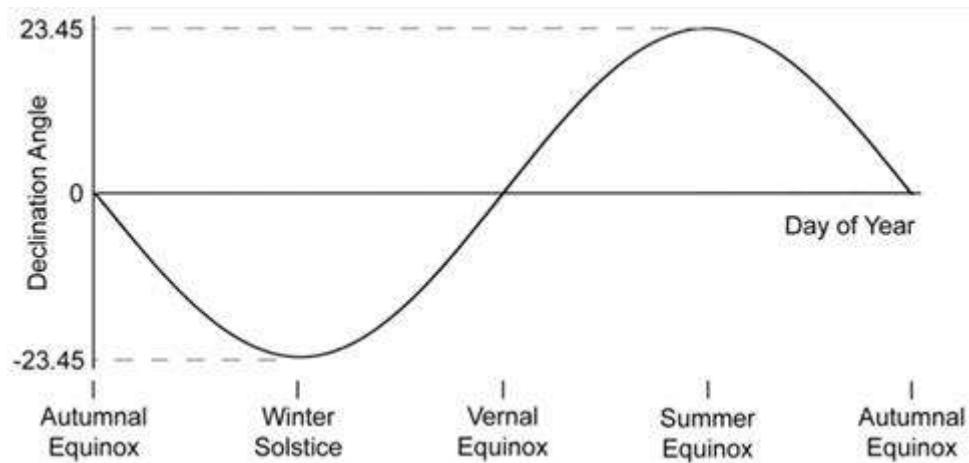


Figure 3.3: The variation in the declination angle throughout the year.

### 3.2.1.3.5 The sunset hour angle $\omega_s$

In order to define the daily amount of energy of solar radiation on surfaces on the Earth, it is necessary to define the time of sunrise and sunset ( $\omega_s$ ) beyond the horizont. In the moment of sunrise (sunset) beyond the horizont the height angle of sun  $\alpha$  has 0 magnitude.

The hour angles at sunrise and sunset ( $\omega_s$ ) are very useful quantities to know. Numerically these two values have the same value however the sunrise angle is (-) negative and the sunset angle is positive (+).

$$\omega_{s\text{sunrise}} = -\omega_s \quad (3.36)$$

$$\omega_{s\text{sunset}} = \omega_s \quad (3.37)$$

The sunset hour angle is given by

$$\omega_s = \arccos[-\tan(\varphi)\tan(\delta)] \quad (3.38)$$

*Note: for calculation results see appendix C.*

**The latitude Angle,  $\varphi$ ,** is the angular distance of the point P north (or south) of the equator as shown in figure 3.4 . It is the angle between the line OP and the projection of OP on the equatorial plane. Point O represents the center of the earth. The sign convention of this, north latitudes are positive and south latitudes are negative.

### Conversion of latitude ( $\varphi$ ) in degrees to radians

The latitude,  $\varphi$ , expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere (see example below). The conversion from decimal degrees to radians is given by:

$$\text{Radians} = \frac{\pi}{180} [\text{Decimal degrees}] \quad (3.39)$$

e.g.1. to convert  $13^{\circ}44'N$  to decimal degrees =  $13 + 44/60 = 13.73$

e.g.2. to convert  $22^{\circ}54'S$  to decimal degrees =  $(-22) + (-54/60) = -22.90$

In applying these equations, attention must be given to correct signs. A summary of the sign convention is:

$\varphi$ : north latitudes are positive, south latitudes are negative

$\delta$ : the declination is positive when the sun's rays are north of the equator, i.e. for the summer period in the northern hemisphere, March 22 to September 22 approximately, and negative when the sun's rays are south of the equator.

$\omega$ : the hour angle is negative before solar noon and positive after solar noon

Z: the sun's azimuth angle is negative east of south and positive west of south

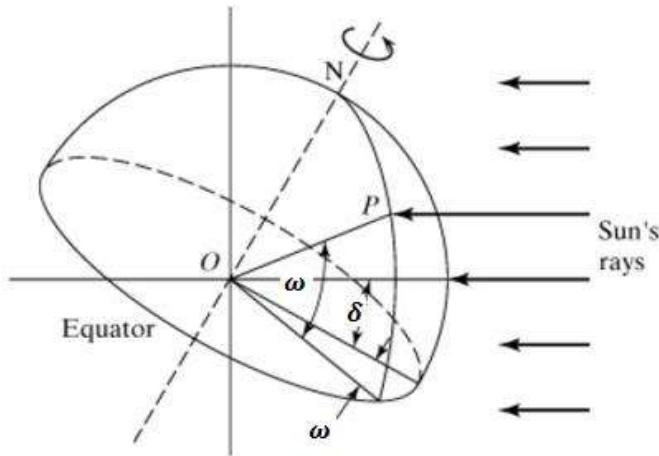


Figure 3.4 : Latitude, hour angle, and sun's declination angle

### 3.2.1.3.6 The number of daylight hours N

The number of daylight hours N for a particular day can be determined by

$$N = \frac{24}{\pi} \omega_s \quad (3.40)$$

Note: for calculation results see appendix C.

Where  $\omega_s$  is in degrees.

Note that there are always 4380 hours of daylight per year (non-leap years) everywhere on the globe.

### 3.2.1.3.7 Solar radiation

The solar radiation is calculated by adjusting the extraterrestrial radiation for the relative sunshine duration

$$R_s = (a_s + b_s \frac{n}{N}) R_a \quad (3.41)$$

Note: for calculation results see appendix D.

Where

$R_s$  = the solar radiation ( $\text{MJ m}^{-2} \text{day}^{-1}$ ),

n = the actual duration of sunshine (hours),

N = the maximum possible amount of sunshine (hours),

and  $a_s$  and  $b_s$  are regression parameters with recommended values of 0.25 and 0.50,

respectively.

### 3.2.1.3.8 Net solar or net shortwave radiation ( $R_{ns}$ )

The effective solar radiation reaching the ground surface resulting from the balance between incoming and reflected solar radiation caused by albedo

$$R_{ns} = (1 - a)R_s \quad (3.42)$$

*Note: for calculation results see appendix D.*

Where

$R_{ns}$  = the net solar or shortwave radiation ( $\text{MJ m}^{-2}\text{day}^{-1}$ ),  
 $a$  = is the albedo of the surface or canopy reflection coefficient,

For open water Shuttleworth (1993)[116] recommends an albedo value of 0.08. However, for shallow evaporation pans the underlying reflectivity of the pan must be considered. For example, dark earthenware or wooden pans filled with water may have an albedo closer to 0.05. When evaporating brine, salt crystals will begin to form, thus increasing the reflectivity. Rife et al. (2002)[117] found that albedo values of 0.3 were appropriate for modeling diurnal weather cycles over a salt-encrusted playa.

### 3.2.1.3.9 Net outgoing long wave solar radiation ( $R_{nl}$ )

The rate of long wave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law. The net energy flux leaving the earth's surface is, however, less than that emitted and given by the Stefan-Boltzmann law due to the absorption and downward radiation from the sky. Water vapor, clouds, carbon dioxide and dust are absorbers and emitters of long wave radiation. It is thereby assumed that the concentrations of the other absorbers are constant:

The net long-wave radiation can be determined by

$$R_{nl} = \sigma \left( \frac{T_{max}^4 + T_{min}^4}{2} \right) (0.34 - 0.14\sqrt{e}) (1.35 \frac{R_s}{(a_s+b_s)R_a} - 0.35) \quad (3.43)$$

*Note: for calculation results see appendix D.*

Where

$R_{nl}$  = net outgoing long wave radiation,  $\text{MJ m}^{-2} \text{ day}^{-1}$ ,  
 $\sigma$  = the Stefan-Boltzmann constant ( $4.903 \cdot 10^{-9} \text{ MJ K}^{-4} \text{ m}^{-2} \text{ day}^{-1}$ ),  
 $T_{max}$  = K maximum absolute temperature during the 24-hour period [ $K = {}^\circ C + 273.16$ ],  
 $T_{min}$  = K minimum absolute temperature during the 24-hour period [ $K = {}^\circ C + 273.16$ ],  
 $e$  = the water vapor pressure (KPa),  
 $a_s$  and  $b_s$  are regression terms mentioned earlier,  
 $R_s$  is the incoming solar radiation ( $\text{MJ m}^{-2} \text{ day}^{-1}$ ),  
 $R_a$  is the extraterrestrial radiation ( $\text{MJ m}^{-2} \text{ day}^{-1}$ ).

### 3.2.1.3.10 The net radiation $R_n$

The net radiation  $R_n$  ( $\text{MJ m}^{-2} \text{ day}^{-1}$ ) is simply the difference between the incoming

effective solar radiation and outgoing long-wave radiation.

$$R_n = R_{ns} - R_{nl} \quad (3.44)$$

*Note: for calculation results see appendix D.*

Where,

$R_{ns}$  = net solar or shortwave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>, [Eq. 3.42].

$R_{nl}$  = net outgoing long wave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>, [Eq. 3.43].

To express the net radiation ( $R_n$ ) in equivalent of evaporation (mm) ( $R_{ng}$ );

$$R_{ng} = 0.408 \times R_n \quad (3.45)$$

Where,

$R_n$  = net radiation, MJ m<sup>-2</sup> day<sup>-1</sup>.[Eq.3.44].

### 3.3 Formulation of mirror system used as a reflector

For overcoming heat loss due to heat transfer from the surface of the solar pond to the atmosphere during nights and also for increasing the solar energy harnessing area during days, a reflection mirror system as shown in Fig.3.5 was designed and used. In this section, a mathematical formulation of this system will be given. For calculating the amount of the sun light energy which is reflected by the reflectors, a mathematical formulation was carried out. In the derivation of the equations, the model seen in Fig. 3.5 was used.

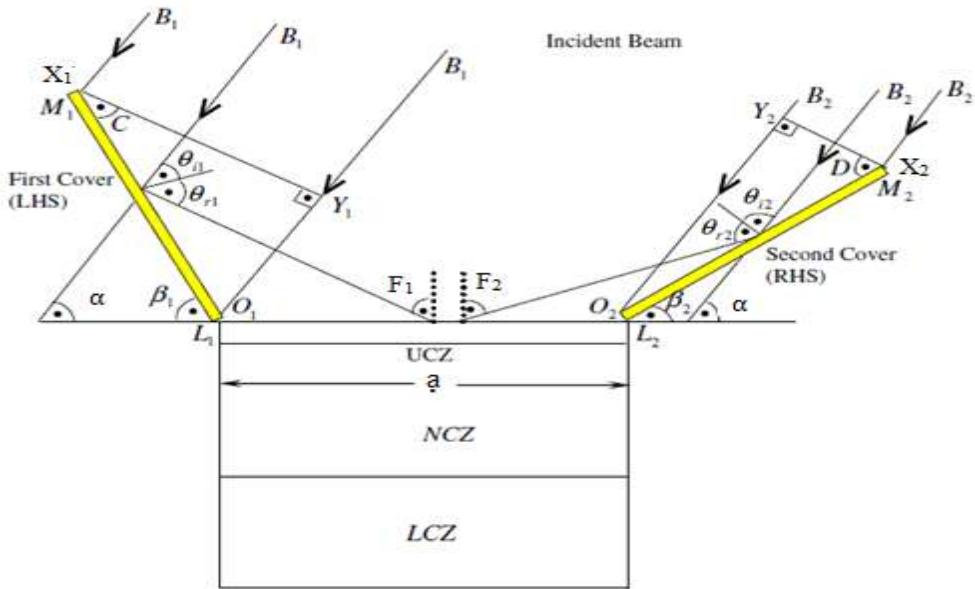


Figure 3.5 : Schematic diagram of the reflectors (adapted from [118]).

As seen from this figure, mirror 1 (LHS reflector) and mirror 2 (RHS reflector) make  $\beta_1$  and  $\beta_2$  angles with horizontal, respectively, and these two angles are the adjustable angles. In this model, the reflectors were considered as two different light sources.  $\alpha$  is the angle between the horizontal surface and the incident light arriving at any hour

of any day of the year.

### 3.3.1 Solar energy reflected by the first mirror

To obtain the expression which gives the amount of the solar energy which will be reflected by the first mirror, the following procedure is followed; to find the amount of the solar energy incident on the surface of this reflector, the front side of the projected area of the reflector normal to the incident light  $X_1Y_1$  is given by

$$X_1Y_1 = M_1L_1 \times \cos C \quad (3.46)$$

*Note: for calculation results see appendix E.*

where:

$C$  = the angle between  $X_1Y_1$  and the reflector and it is a function of time.

$M_1L_1$  = the side length of the reflector.  $C$  is given by

$$C = 90 - [180 - \alpha - \beta_1] = 90 - 180 + \alpha + \beta_1 = -90 + \alpha + \beta_1 \quad (3.47)$$

*Note: for calculation results see appendix E.*

Substituting  $C$  in Eq. (3.47), the length of  $X_1Y_1$  in the triangle,  $X_1Y_1O_1$ , is

$$X_1Y_1 = M_1L_1 \times \cos(-90 + \alpha + \beta_1) \quad (3.48)$$

The projection area of the reflector normal to the incident light,  $SM_1$ , is

$$SM_1 = X_1Y_1 \times a \quad (3.49)$$

where  $a$  is the length of one side of the pond or the length of the reflector.

Substituting the value of  $X_1Y_1$  given

$$SM_1 = M_1L_1 \times \cos(-90 + \alpha + \beta_1) \times a \quad (3.50)$$

*Note: for calculation results see appendix E.*

The amount of the solar energy which will be reflected by the first reflector into the solar pond is

$$G_1 = SM_1 \times B_1 \quad (3.51)$$

*Note: for calculation results see appendix E.*

where  $B_1$  is amount of the solar energy falling on one-meter square area perpendicular to the incident light per unit time and it is equal to  $B_2$ . The amount of the solar energy which will fall on one-meter square area of the solar pond in per unit time,  $U_1$ , is obtained using  $G_1$

$$U_1 = G_1 / a^2 \quad (3.52)$$

Or

$$U_1 = M_1L_1 \times \cos(-90 + \alpha + \beta_1) \times B_1 / a \quad (3.53)$$

*Note: for calculation results see appendix E.*

### 3.3.2 Solar energy reflected by the second mirror

Following the similar way an expression which will give the amount of the energy to be reflected from the other reflector,  $U_2$ , is

$$U_2 = M_1 L_1 \times \cos(90 + \alpha + \beta_2) \times B_1 / \varrho \quad (3.54)$$

*Note: for calculation results see appendix F.*

where  $M_1 L_1$  is equal to  $M_2 L_2$ .

In the computational modeling, it is necessary to know the angles between the light beams coming from reflectors and the normal of the surface of the solar pond. These angles were denoted by  $F_1$  and  $F_2$ , respectively, and their expressions have been obtained using the geometry of the system shown in Fig. 3.5 in terms of  $\varepsilon$ ,  $\beta_1$  and  $\beta_2$

$$F_1 = 90 + \alpha - 2\beta_1 \quad (3.55)$$

*Note: for calculation results see appendix E.*

and

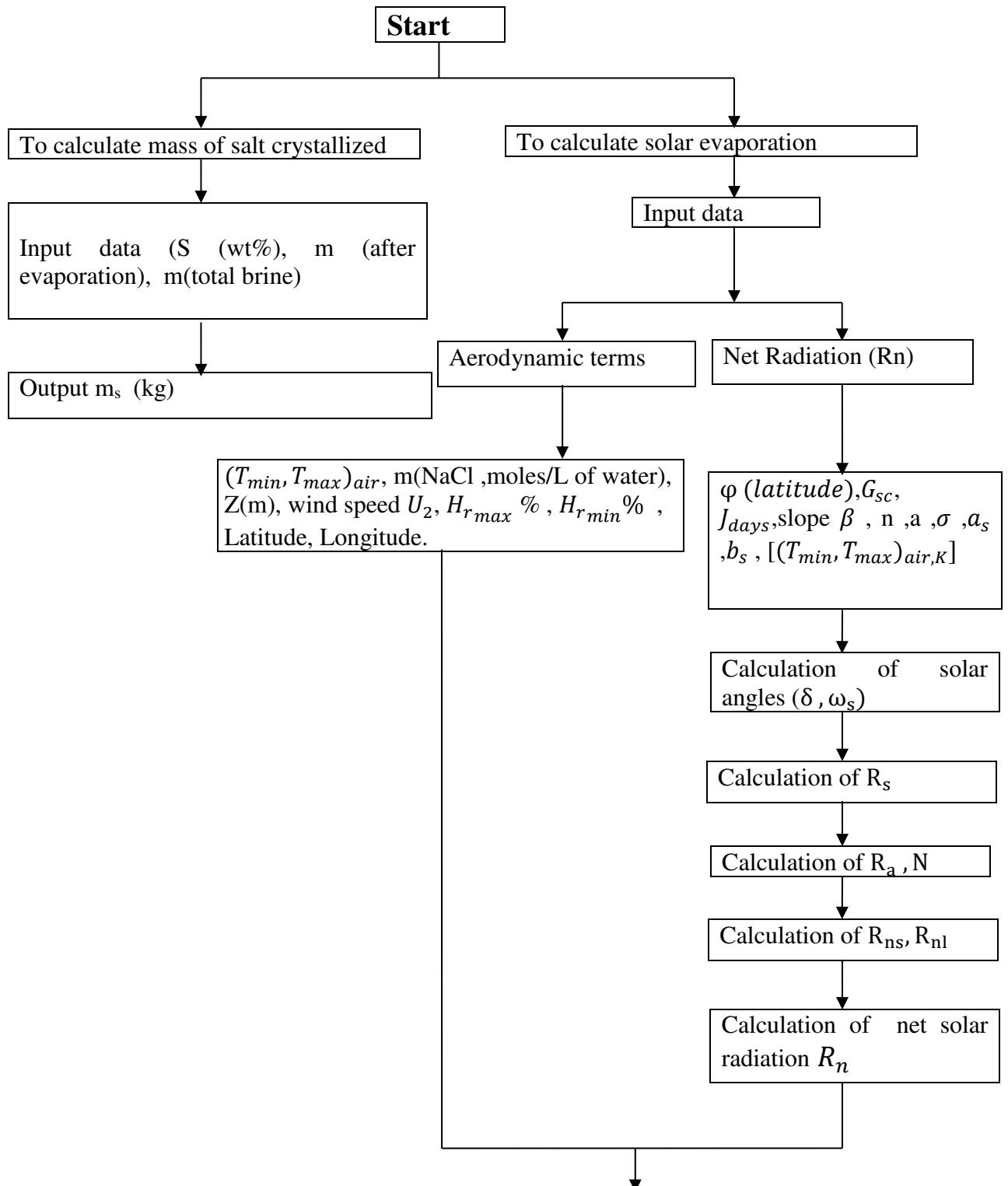
$$F_2 = 270 - 2\beta_2 - \alpha \quad (3.56)$$

*Note: for calculation results see appendix F.*

These equations have been used in the theoretical model calculations. In order to model the solar pond with mirrors, numerical solution of the equations, defining how much energy is incoming from reflectors to the pond surface, is implemented to our existing code [119,120].

### 3.4 Calculation procedure

This section shows the sequence to calculate the amount of output salt and the resulting rate of evaporation.



## Chapter 4 : Materials and Methods

### 4.1 Detailed description of the construction of SSP

A schematic diagram of the constructed small scale SSP is shown in Figure 4.1 and as a photo in Figure 4.2

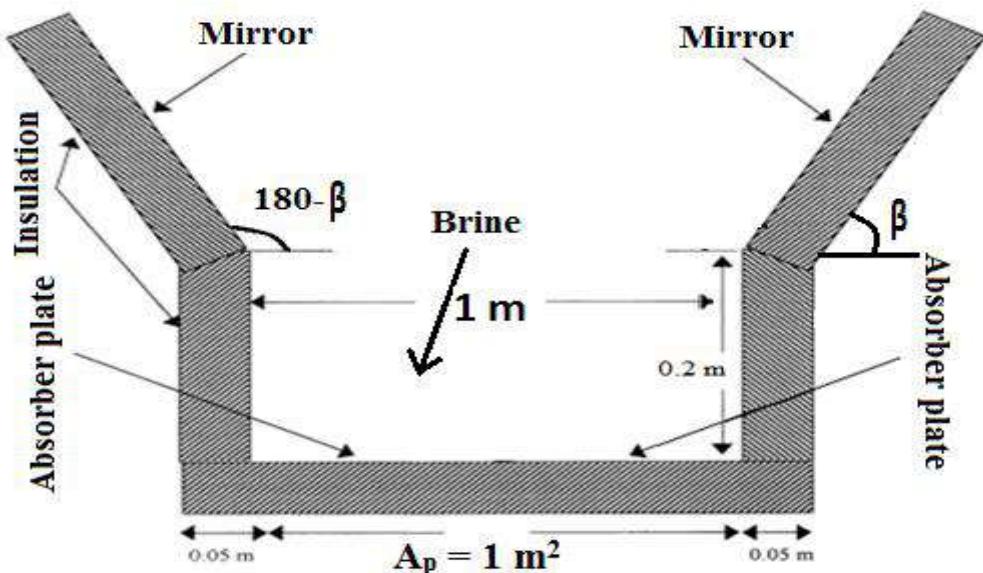


Figure 4.1: SSP schematic diagram



Figure 4.2: Photographic of Locally Fabricated SSP

The locally made shallow solar pond is shown in Figure 4.2 consists of the following components were fabricated using locally sourced materials is described as follows:

#### 4.1.1 wooden box

The SSP with a depth of 0.2 m and a bottom surface area of 1.0 m<sup>2</sup> was constructed from wooden box that was created in Carpentry Timber.(Figure 4.3).

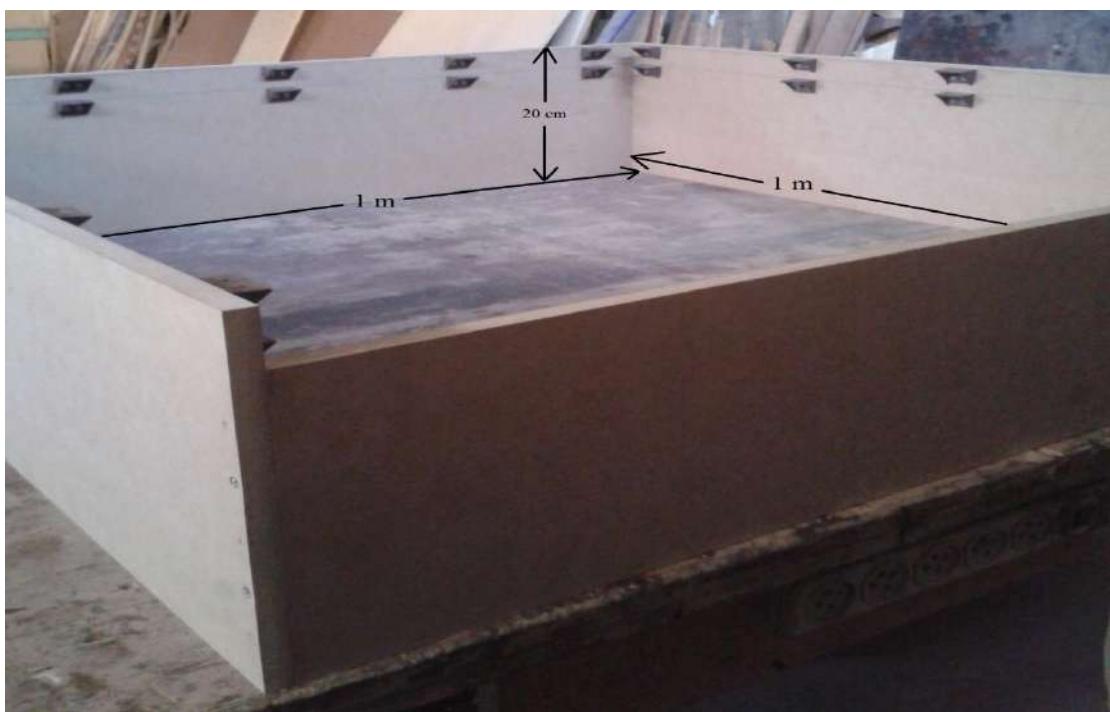


Figure 4.3 : The wooden box for SSP

#### 4.1.2 Galvanized iron sheet

A galvanized-iron sheet (0.001m thick) was used for fabricating the pond with a depth of 0.2 m and a bottom surface area  $A_p$  of 1  $m^2$ , which acts as the absorbing surface for the incident solar radiation of the pond as shown in Figure 4.4.



Figure 4.4 : Galvanized iron sheet

The surface of the absorber plate exposed to the sun was painted by black paint to maximize the amount of the absorbed solar radiation (Figure 4.5).



Figure 4.5 : The painting of absorber plate

#### 4.1.3 layer of sawdust

In order to minimize the heat losses from the sides and back of the SSP, a 0.05 m thick layer of sawdust was used as an insulating material as shown in Figure 4.6.

For choosing the insulation material following properties were considered: It should withstand the maximum temperature anticipated in the pond. It should be resistant to ultraviolet radiations. It should not react with the salt. The metallic box and the

insulating layer are contained in a wooden frame.

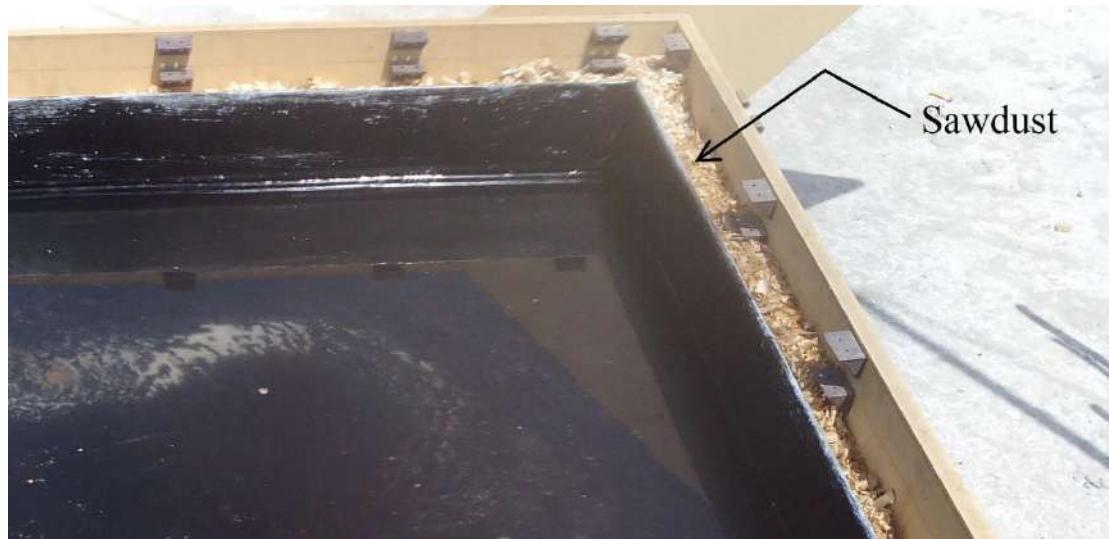


Figure 4.6 : Layer of sawdust

#### 4.1.4 Plane Mirror

A movable plane mirror with an area equal to that of the pond surface ( $1 \text{ m}^2$ ) is hinged at the top of the pond to increase the intensity of solar radiation incident on the pond cover (Figure 4.7) and to improve the thermal performance of the pond. The mirror was also used as an insulation cover for the pond during the night by using 0.05m thick layer of sawdust lying between the back surface of the mirror and a wooden sheet. The angle  $\beta$  between the mirror and the horizontal is usually adjusted to increase the amount of solar radiation reflected to the pond.(Figure 4.8).

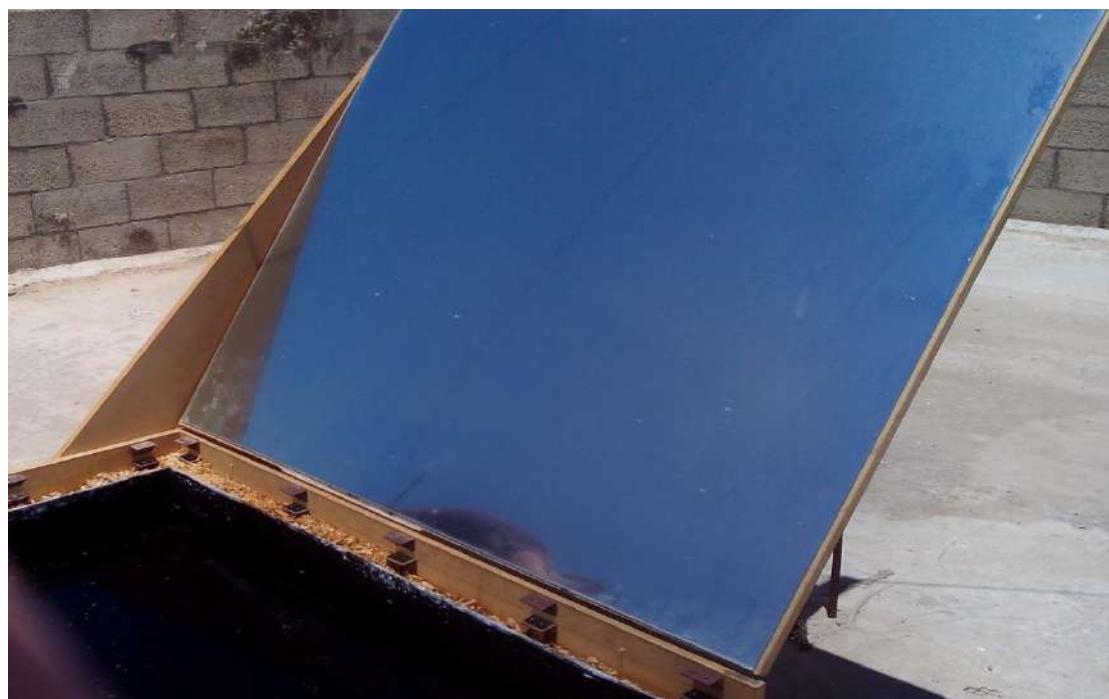


Figure 4.7 : Plane mirror



Figure 4.8 : Adjustable angle  $\beta$ .

## 4.2 Experimental procedure

**The experiment was carried out using the following steps:**

- The experiments were carried out outdoors from 12 AM to 12 PM for 11 successive days (12–22 July) of the summer season of the year 2015.
- To follow-up the brine evolution, brine sample from the seawater desalination plant located in Deir Al-Balah was collected to determine its chemical constituents. The climate at the site was always wet and hot with no rain fall during the studied period.
- The brine sample was collected in clean bottles without any air bubbles. The bottles were tightly sealed and labeled outside in the field and constantly weighed as shown in Figure 4.9.



Figure 4.9 : Brine samples collected in bottles

- The pond is filled with natural brine at 12 AM by continuous addition of brine until the pond becomes completely filled with brine to an initially depth of 0.075 m inside the SSP (Figure 4.10).



Figure 4.10 : Initial depth of brine sample

- The level of water in the pond was fixed at 12 cm by using an overflow system consisting of PVC pipe with 2 inches diameter as shown in Figure 4.11.



Figure 4.11 : Overflow system

- The system was oriented to face south to maximize the solar radiation received by the pond.

- The ambient air temperature and Relative humidity conditions, wind speed and solar radiation at which the experimental work were done, recorded every 1 hour during the day at the field work by means of an computerized automatic weather data (<http://www.accuweather.com>).

- Brine is heated by solar radiation and thus it gets evaporated, the levels of water in the studied solar pond were measured in situ every 24 hours (1 day) using ruler, then

Evaporation rates determined by the difference between initial and final readings.(Figure 4.12).

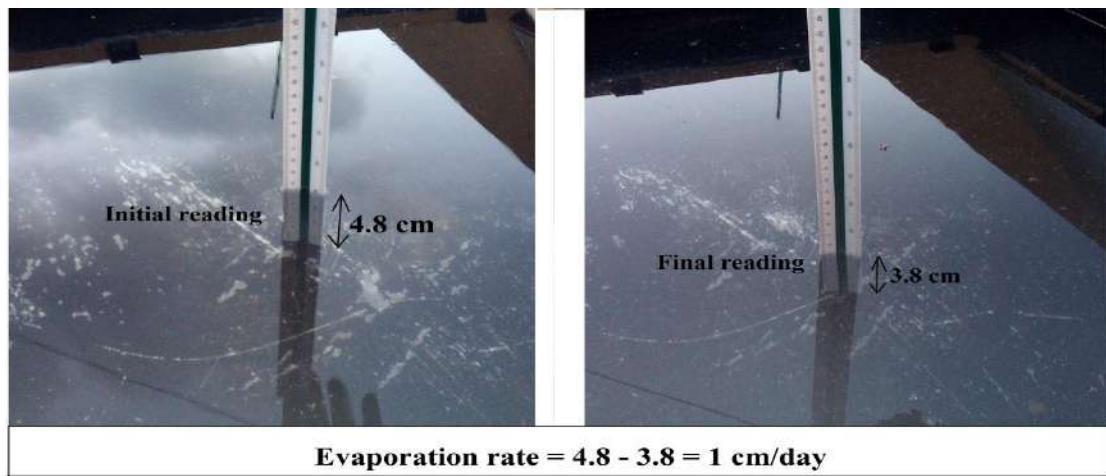


Figure 4.12 : Readings of water level

- During evaporation process, brine samples were taken in sequence at different densities for chemical analysis.
- All brine samples were analyzed for major ions ( $\text{Na}^+$ , and  $\text{Cl}^-$ ) by titration, pH and total dissolved solids TDS were determined by pH and TDS meters respectively.
- To evaluate theoretically and experimentally the performance of the solar pond, the design of the evaporation pond was accomplished using three distinct scenarios:
  - 1- The first scenario was used two reflecting mirrors with five different angles for both mirrors, this scenario extending for five days from 12 to 16 July 2015 (Figure 4.13).
  - 2- The second scenario was without using any mirrors at 17 July 2015.
  - 3- The third scenario was by using one reflecting mirror with five different angles extending for five days from 18 to 22 July 2015.

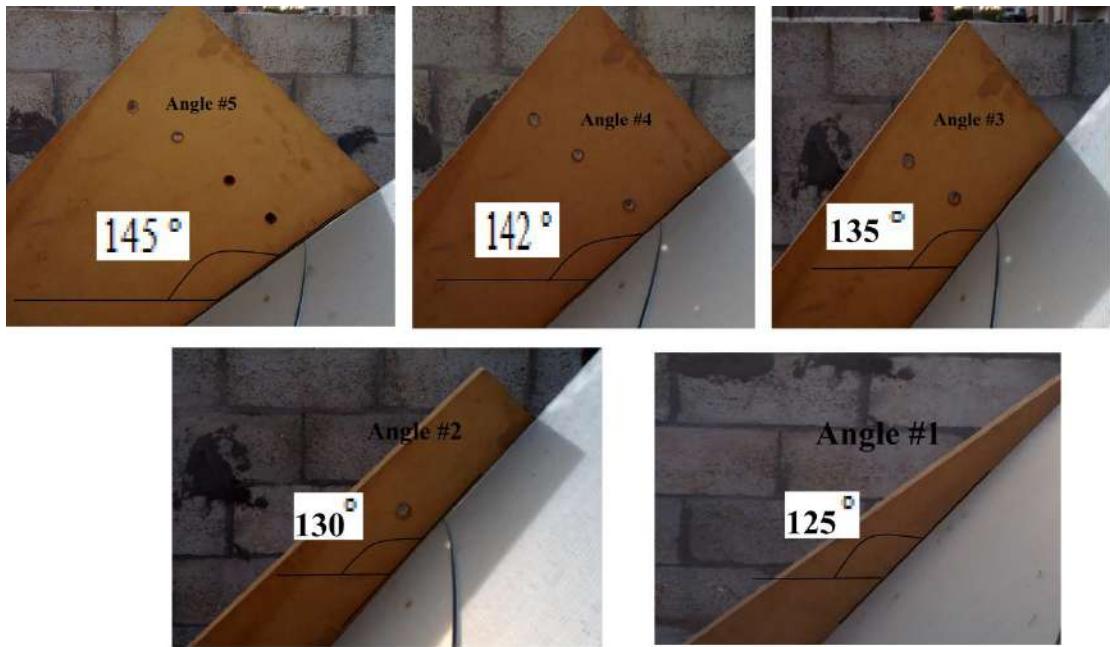


Figure 4.13: Angles of mirrors

- The daily rate of evaporation of the solar pond for each scenario is then calculated with the aid of Eqs. (3.4 or 3.46). The theoretically and experimentally results then compared with each other.
- A computer program was prepared for the solution of the evaporation rate equations for the solar pond. The input parameters to the computer program include climatic, and design parameters. Another computer exercise has been performed for calculating the total solar-radiation incident on the mirror and that reflected to the pond.
- The same procedure is repeated with new values of different climatic conditions for every day through the experiments and so on.

## Chapter 5: Results and Discussions

### 5.1 Effect of brine salinity on salt (NaCl) output:

To illustrate the utility of predicting salt-making process, brine sample was collected from the desalination plant. Sample No.1 have NaCl concentration differ than that of sample No. 2 as shown in table 5.1. Note that sample No. 2 collected and analyzed after 10 days during the experiment of brine evaporation.

Table 5.1: Brine chemical analysis

No.	Test	Unit	Sample No. 1	Sample No. 2
1	PH	-	7.78	8.03
2	TDS	Mg/L	63360	-
3	EC	µs	99000	>199000

4	$\text{Cl}^{-1}$	Mg/L	35600	100000
5	$\text{Na}^{+1}$	Mg/L	37622	60774

The first sample takes 10 days of evaporation to concentrate the brine sufficiently to begin collecting salt, about 8.03 kg are then collected at the end of the period. The second sample produced about 6.77 kg of salt and took about 8 days. The total amount of 14.8 kg of salt was produced from salt-making process during the experiment period. There is an increased amount of salt about 15.7% when salinity increased from 73222mg/l to 160774mg/l.

The experiments are continued every day until the level of water decreasing and becomes equal to zero and the layers of salt begin to appear as shown in Figure 5.1.

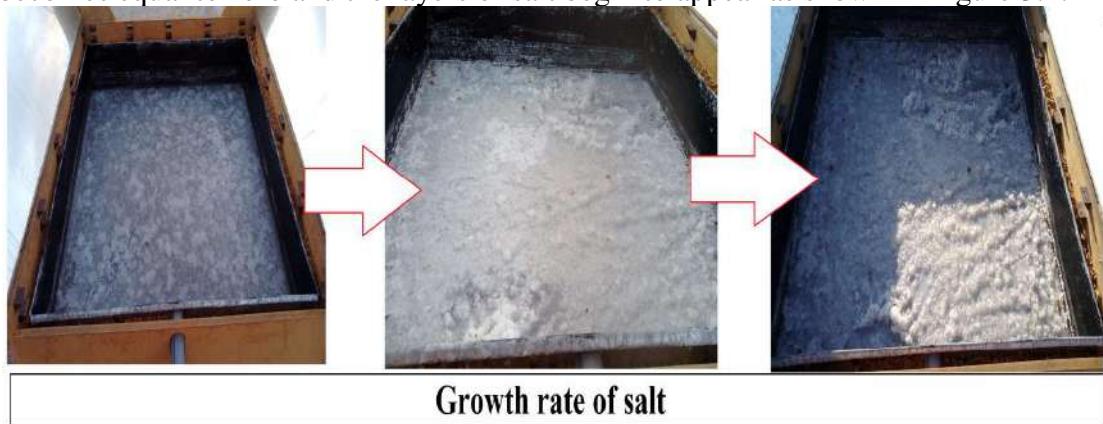


Figure 5.1 : Growth rate of salt

- The salt (solid) samples were collected in small polyethylene plastic bags and tightly sealed and labeled in the field to be weighed using an electronic balance and for examination techniques (Figure 5.2). The salt samples were carefully kept away from any atmospheric conditions until examinations.



Figure 5.2 : Output Salt samples

## 5.2 Solar evaporation rates process:

In this section, the results obtained from the model and experiment were discussed and compared with each other, and then the effects of the various parameters were examined.

To illustrate the utility of predicting solar evaporation rates, using the steps outlined in chapter 3 were numerically analysis the evaporation process using three distinct scenarios. The first scenario was used two reflecting mirrors with five different angles for both mirrors, this scenario extending for five days from 12 to 16 July 2015, the second scenario was not used any mirrors (without mirror) in 17 July 2015, and the third scenario was used one reflecting mirror with five different angles extending for five days from 18 to 22 July 2015.

Each scenario requires a weather data and site specific information file that were created using the measured data covering the period from 12 to 22 July 2015 at which the experimental work was done derived. The online databases were recorded every 1 hour during the day at the field work by means of an automatic weather data (<http://www.accuweather.com>), and used as an input to the computer excel model. Solar radiation, ambient air temperatures, relative humidity RH and wind speed were recorded every one hour. Evaporation were observed in situ daily using a scale ruler. Hourly evaporation was approximated by using penman equation explained in chapter 3 for each hour and proportioning the distribution of the daily total evaporation to the 24 h period.

Table 5.2 shows the average hourly ambient air temperature, maximum ambient air temperature and minimum ambient air temperature for the three scenarios as follows:

Scenario	Date	Average ambient air temperature, °C	Maximum ambient air temperature, °C	Minimum ambient air temperature, °C
Two mirrors	12/7/2015	26.71	32	22
	13/7/2015	27.04	33	22
	14/7/2015	27.75	34	23
	15/7/2015	26.54	30	24
	16/7/2015	27.625	34	21
Without mirror	17/7/2015	27.54	34	22
One mirror	18/7/2015	27.623	32	24
	19/7/2015	27.875	33	23
	20/7/2015	27.54	33	23
	21/7/2015	27.875	33	22
	22/7/2015	28.21	35	23

### **5.2.1 Effect of meteorological variables on evaporation rate of shallow solar pond:**

There are many factors of meteorological conditions, such as solar radiation, relative humidity, ambient air temperature, and wind speed which may be affect on solar evaporation rate.

### 5.2.1.1 Effect of solar radiation, MJ.m<sup>-2</sup>.day<sup>-1</sup>

The effect of solar radiation is given in this section. The effect of solar radiation was pronounced on the results of evaporation rates for the three scenarios that are explained next. The results obtained from the model and experiment were discussed and compared with each other.

- **First scenario: Solar pond without using any mirror:**

Table 5.3 shows Comparison between actual and theoretical evaporation rate in 17/7/2015 when average solar radiation was 10.48 MJ /m<sup>2</sup>/d in case of without using any mirror. By comparing these values, there is little difference of evaporation rate about 0.1 mm and can be neglected.

Date	Average Rs (MJ /m <sup>2</sup> /d)	Theoretical Evaporation rate (mm/d)	Actual Evaporation rate (mm/d)
17/7/2015	10.48	2.6	2.5

- **Second scenario: Solar pond using one reflector mirror:**

Chart 5.1 shows the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 18 to 22 July 2015 using one reflector mirror in solar pond. By comparing experimental and theoretical values using one reflector mirror, there were little differences of evaporation rates (mm/d) of 0.24, 0.4, 0.35, 0.46 and 0.59, respectively.

It is noted that the actual rate of evaporation using one mirror was less than the theoretical evaporation rate.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient r value was 0.998.

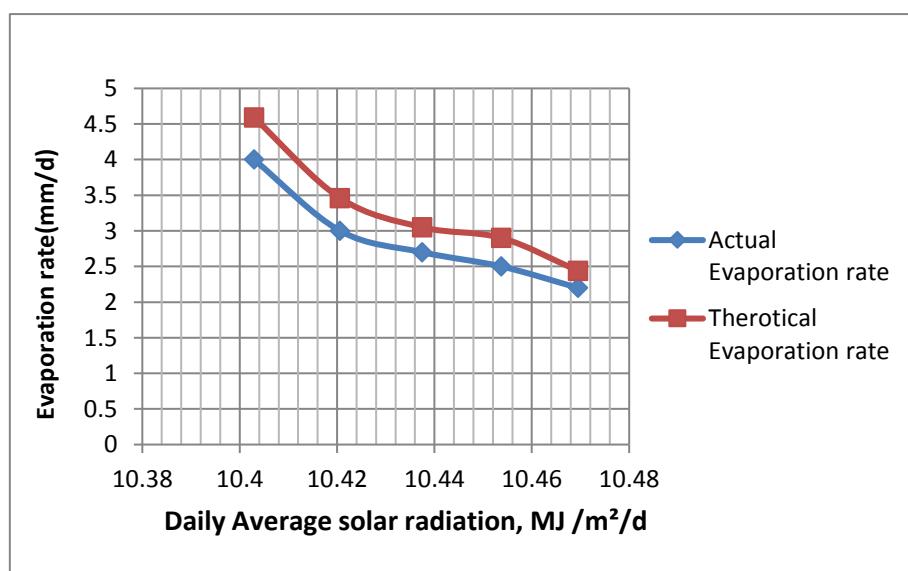


Chart 5.1 : Actual and theoretical evaporation rate at different five daily average solar radiation (MJ /m<sup>2</sup>/d) in case of using one mirror.

- **Third scenario: Solar pond using two reflector mirrors:**

Chart 5.2 shows the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 12 to 16 July 2015 using two reflector mirrors in solar pond. By comparing experimental and theoretical values using two reflector mirrors, there was little differences of evaporation rates (mm/d) of 0.35, 0.34, 0.12, 0.2 and 0.14, respectively.

It is noted that the actual rate of evaporation rate using two mirrors increases than the theoretical evaporation rate.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient  $r$  value was 0.996.

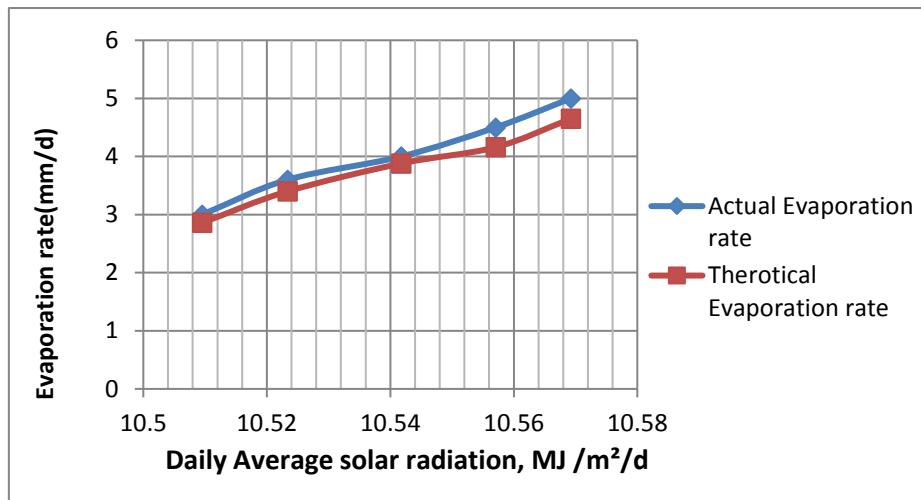


Chart 5.2 : Actual and theoretical Evaporation rate at different five daily average solar radiation (MJ /m<sup>2</sup>/d) in case of using two mirrors.

#### **5.2.1.1.1 Effect of solar radiation at different angles on evaporation rate:**

- **First scenario: Solar pond using one reflector mirror:**

Chart 5.3 shows the effect of solar radiation on evaporation rate using one reflector mirror in solar pond when angle  $\beta$  is changeable. Little of decreasing the evaporation rate with increasing of solar radiation. It can be seen from Chart 5.3 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal.

To get accurate mathematical expression of the relation between solar radiation and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (One mirror) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for solar radiation regression model using one mirror are shown in table 5.4. The coefficient of determination  $R^2$  represents that 77% of the data is closest to the line of best fit.

$\beta$ 2	Resulted equations	Coefficient of determination, $R^2$
-----------	--------------------	-------------------------------------

$35^\circ$	$E(\text{mm/d}) = 282.76Rs^2 - 5916.6 \text{ Rs} + 30953$	$R^2 = 0.778$
$38^\circ$	$E(\text{mm/d}) = 296.4Rs^2 - 6200.8 \text{ Rs} + 32434$	$R^2 = 0.7769$
$45^\circ$	$E(\text{mm/d}) = 325.53Rs^2 - 6807.9 \text{ Rs} + 35597$	$R^2 = 0.7749$
$50^\circ$	$E(\text{mm/d}) = 349.93Rs^2 - 7316.4 \text{ Rs} + 38247$	$R^2 = 0.774$
$55^\circ$	$E(\text{mm/d}) = 361.07Rs^2 - 7548.6 \text{ Rs} + 39455$	$R^2 = 0.7712$

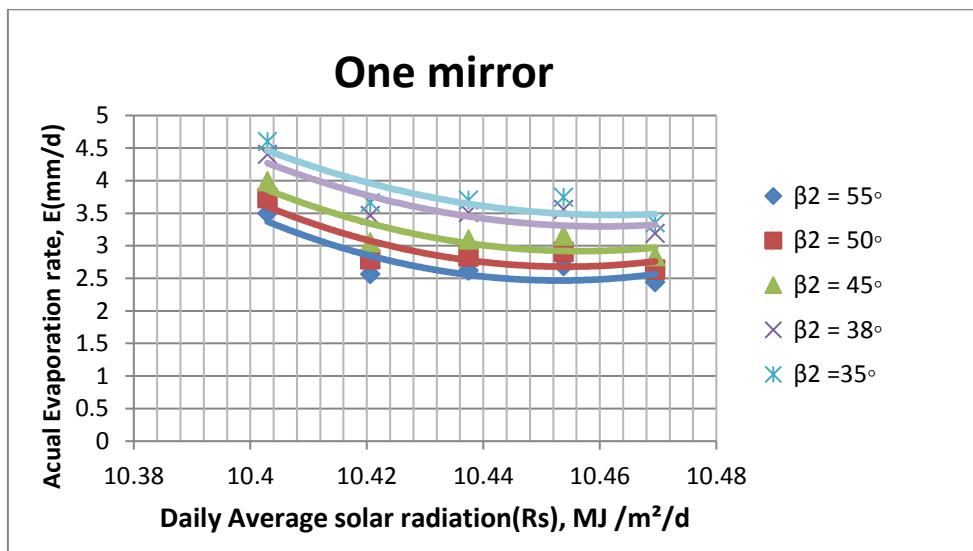


Chart 5.3 : Effect of solar radiation (MJ /m<sup>2</sup>/d) on evaporation rate using one reflector mirror in solar pond.

#### - Second scenario: Solar pond using two reflector mirrors:

Chart 5.4 shows the effect of solar radiation on evaporation rate using two reflector mirrors in solar pond when angle  $\beta$  is changeable. Gradual increasing of evaporation rate with increasing solar radiation using two reflector mirrors. It can be seen from Chart 5.4 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal.

To get accurate mathematical expression of the relation between solar radiation and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (Two mirrors) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for solar radiation regression model using two mirrors are shown in table 5.5. The coefficient of determination  $R^2$  represents that the data is very closest to the line of best fit.

$\beta_1 = \beta_2$	Resulted equations	Coefficient of determination $R^2$
---------------------	--------------------	------------------------------------

$35^\circ$	$E(\text{mm/d}) = 474.56Rs^2 - 9987.4(Rs) + 52551$	$R^2 = 0.9387$
$38^\circ$	$E(\text{mm/d}) = 483.76Rs^2 - 10182(Rs) + 53579$	$R^2 = 0.876$
$45^\circ$	$E(\text{mm/d}) = 282.21Rs^2 - 5930.2(Rs) + 31158$	$R^2 = 0.9905$
$50^\circ$	$E(\text{mm/d}) = 193.51Rs^2 - 4054.8(Rs) + 21244$	$R^2 = 0.998$
$55^\circ$	$E(\text{mm/d}) = 124.4Rs^2 - 2591.4(Rs) + 13497$	$R^2 = 0.9997$

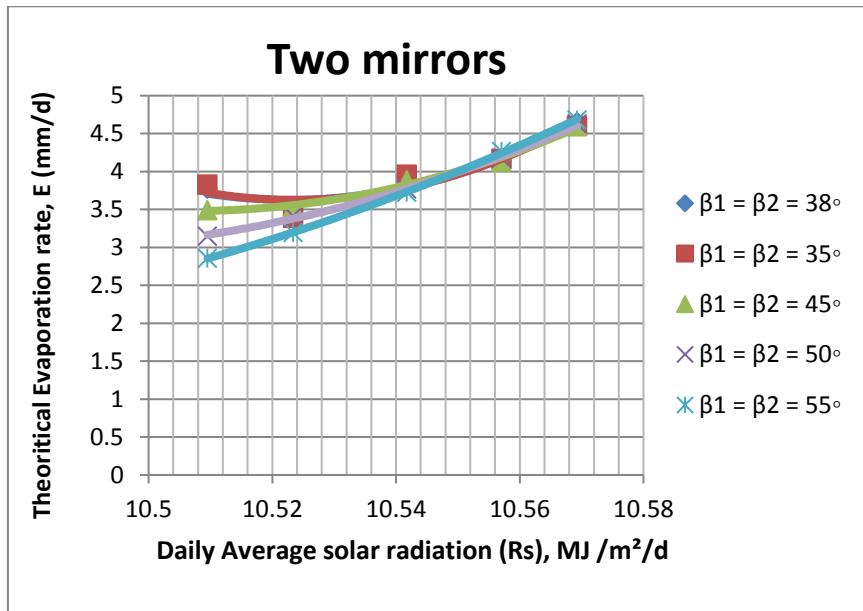


Chart 5.4 : Effect of solar radiation (MJ /m<sup>2</sup>/d) on evaporation rate using two reflector mirrors in solar pond.

### 5.2.1.2 Effect of relative humidity, Hr%

The effect of relative humidity is given in this section. The effect of relative humidity was pronounced on the results of evaporation rates for the three scenarios that are explained next. The results obtained from the model and experiment are discussed and compared with each other.

- **First scenario: Solar pond without using any mirror:**

Table 5.6 shows comparison between actual and theoretical evaporation rate in 17/7/2015 when average relative humidity was 60.79 in case of without using any mirror. By comparing these values, there is little difference of evaporation rate about 0.1 mm and can be neglected.

Date	Average % RH	Theoretical Evaporation	Actual Evaporation rate
------	--------------	-------------------------	-------------------------

		rate (mm/d)	(mm/d)
17/7/2015	60.79	2.6	2.5

- **Second scenario: Solar pond using one reflector mirror:**

Chart 5.5 shows the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 18 to 22 July 2015 using one reflector mirror in solar pond. By comparing between experimental and theoretical values using one reflector mirror, there is little difference of evaporation rates (mm/d) of 0.24, 0.4, 0.35, 0.46 and 0.59, respectively.

It is noted that the actual rate of evaporation rate using one mirror less than the theoretical evaporation rate.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient r value was 0.998.

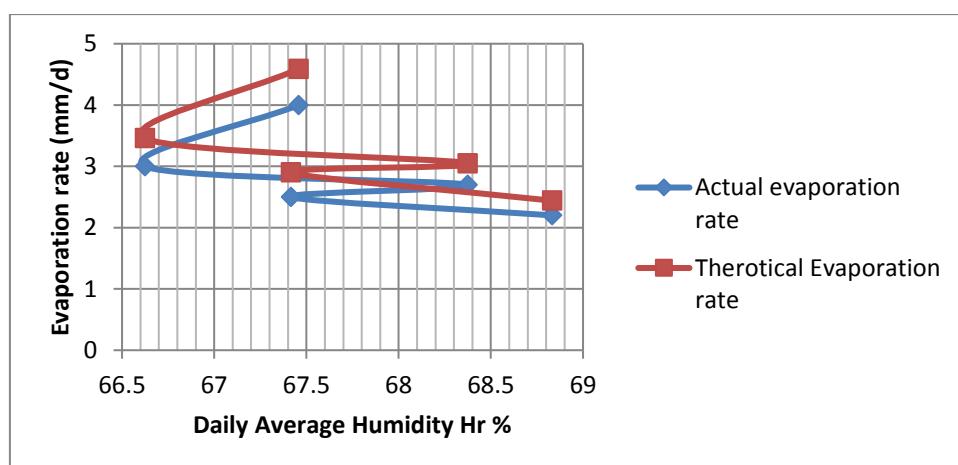


Chart 5.5 : Actual and theoretical evaporation rate at different five daily average relative humidity % in case of using one mirror.

- **Third scenario: Solar pond using two reflector mirrors:**

Chart 5.6 shows the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 12 to 16 July 2015 using two reflector mirrors in solar pond. By comparing between experimental and theoretical values using two reflector mirrors, there is little difference of evaporation rates (mm/d) about 0.35, 0.34, 0.12, 0.2 and 0.14, respectively.

It is noted that the actual rate of evaporation rate using two mirrors increases than the theoretical evaporation rate.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient r value is 0.996.

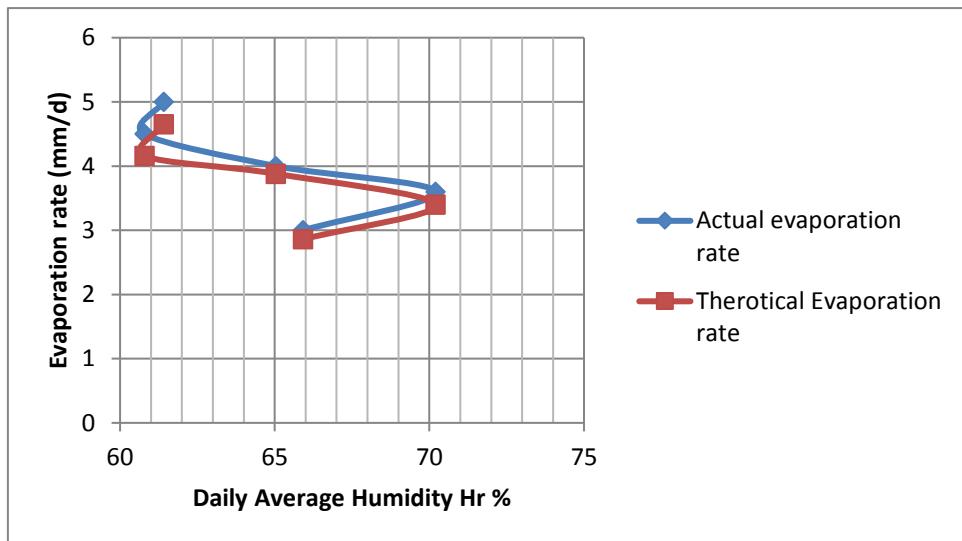


Chart 5.6 : Actual and theoretical Evaporation rate at different five daily average relative humidity % in case of using two mirrors.

#### **5.2.1.2.1 Effect of relative humidity at different angles on evaporation rate:**

- **First scenario: Solar pond using one reflector mirror:**

Chart 5.7 shows the effect of relative humidity on evaporation rate using one reflector mirror in solar pond when angle  $\beta$  is changeable. Little of increasing the evaporation rate until it reach the maximum at relative humidity of 67.6%. After that, evaporation rates shows a slight decrease with increasing of relative humidity. It can be seen from Chart 5.7 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal. Table 5.7 shows the maximum evaporation rates observed at 67.6% RH for different five successive mirror's angle makes with horizontal  $\beta$ .

To get accurate mathematical expression of the relation between relative humidity and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (One mirror) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for relative humidity regression model using one mirror are shown in table 5.7. The coefficient of determination  $R^2$  represents that the data is moderately correlated to the line of best fit.

$\beta$ 2	Resulted equations	Coefficient of determination, $R^2$	Max. evaporation rate (mm/d) at 67.6% RH
$35^\circ$	$E(\text{mm/d}) = -0.5336(\text{RH}\%)^2 + 72.119(\text{RH}\%) - 2432.5$	$R^2 = 0.5685$	4.32
$38^\circ$	$E(\text{mm/d}) = -0.523(\text{RH}\%)^2 + 70.686(\text{RH}\%) - 2384.5$	$R^2 = 0.5563$	3.88
$45^\circ$	$E(\text{mm/d}) = -0.4991(\text{RH}\%)^2 + 67.474(\text{RH}\%) - 2276.8$	$R^2 = 0.527$	3.67
$50^\circ$	$E(\text{mm/d}) = -0.4811(\text{RH}\%)^2 + 65.047(\text{RH}\%) - 2195.5$	$R^2 = 0.5011$	3.16
$55^\circ$	$E(\text{mm/d}) = -0.4706(\text{RH}\%)^2 + 63.646(\text{RH}\%) - 2148.7$	$R^2 = 0.4864$	3.24

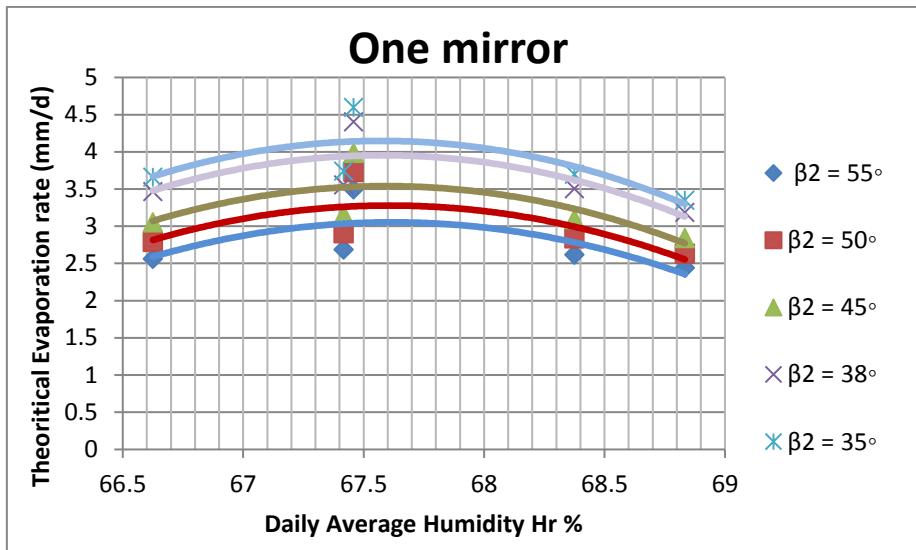


Chart 5.7 : Effect of relative humidity on evaporation rate using one reflector mirror in solar pond.

- **Second scenario: Solar pond using two reflector mirrors:**

Chart 5.8 shows the effect of relative humidity on evaporation rate using two reflector mirrors in solar pond when angle  $\beta$  is changeable. Little of decreasing the evaporation rate was observed by increasing relative humidity. It can be seen from Chart 5.8 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal.

To get accurate mathematical expression of the relation between relative humidity and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (Two mirrors) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for relative humidity regression model using two mirrors are shown in table 5.8. The coefficient of determination  $R^2$  represents that the data is closest to the line of best fit.

$\beta_1 = \beta_2$	Resulted equations	Coefficient of determination, $R^2$
$35^\circ$	$E(\text{mm/d}) = 23.302e^{-0.027(\text{RH}\%)}$	$R^2 = 0.8652$
$38^\circ$	$E(\text{mm/d}) = 20.763e^{-0.026(\text{RH}\%)}$	$R^2 = 0.8022$
$45^\circ$	$E(\text{mm/d}) = 0.0103^{(\text{RH}\%)^2} - 1.4465^{(\text{RH}\%)} + 54.231$	$R^2 = 0.7355$
$50^\circ$	$E(\text{mm/d}) = 0.0193^{(\text{RH}\%)^2} - 2.6512^{(\text{RH}\%)} + 94.147$	$R^2 = 0.7589$
$55^\circ$	$E(\text{mm/d}) = 0.024^{(\text{RH}\%)^2} - 3.2931^{(\text{RH}\%)} + 116.14$	$R^2 = 0.7842$

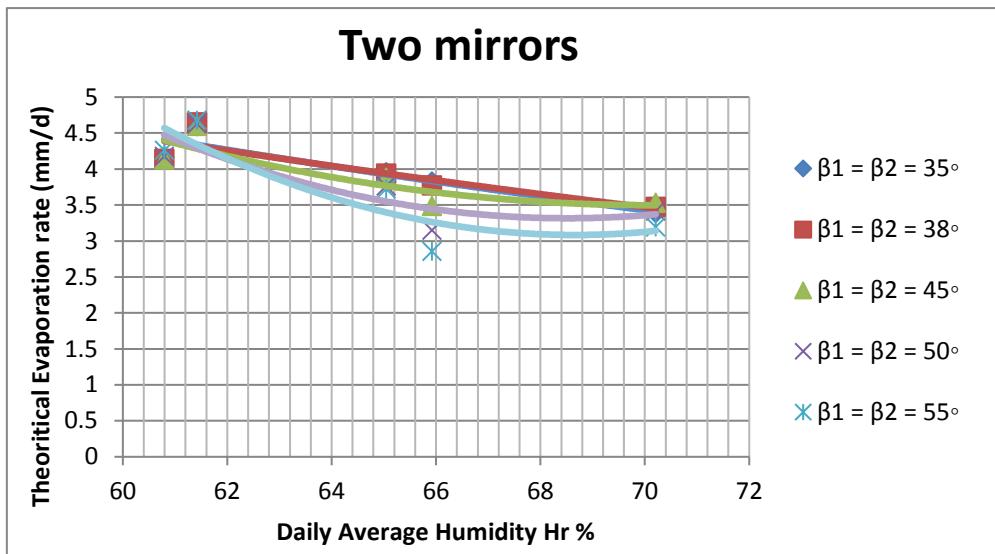


Chart 5.8 : Effect of relative humidity on evaporation rate using two reflector mirrors in solar pond.

Finally, Charts 5.7 and 5.8 show that when daily average humidity was 66% and the mirror's angle makes with horizontal was 55°, 50°, 45°, 38° and 35°, the evaporation rate resulted were 1.93 mm, 2mm, 2.4mm, 2.6mm and 2.99mm respectively when using one mirror and 3.24mm, 3.34mm, 3.63mm, 3.73mm and 3.92mm respectively when using two reflector mirrors. This is about 40.4%, 40.04% ,33.7% ,30.7% and 23.7% respectively. Improvement in the efficiency of the solar pond on evaporation rate was observed by using two reflector mirrors as compared with solar pond used one reflector mirror.

#### 5.2.1.3 Effect of ambient air temperature, °C :

The effect of ambient air temperature is given in this section. The effect of ambient air temperature was pronounced on the results of evaporation rates for the three scenarios that are explain next. The results obtained from the theoretical model and experiment are discussed and compared with each other.

- **First scenario: Solar pond without using any mirror:**

Table 5.9 shows comparison between actual and theoretical evaporation rate in 17/7/2015 when average ambient air temperature was 28°C in case of without using any mirror. By comparing these values, there was little difference of evaporation rate of about 0.1 mm and can be neglected.

Date	Average ambient air Temp, °C	Theoretical Evaporation rate (mm/d)	Actual Evaporation rate (mm/d)
17/7/2015	28	2.6	2.5

- **Second scenario: Solar pond using one reflector mirror:**

Chart 5.9 shows the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 18 to 22 July 2015 using one

reflector mirror in solar pond. By comparing between experimental and theoretical values using one reflector mirror, there is little difference of evaporation rates (mm/d) about 0.24, 0.4, 0.35, 0.46 and 0.59, respectively.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient r value is 0.998.

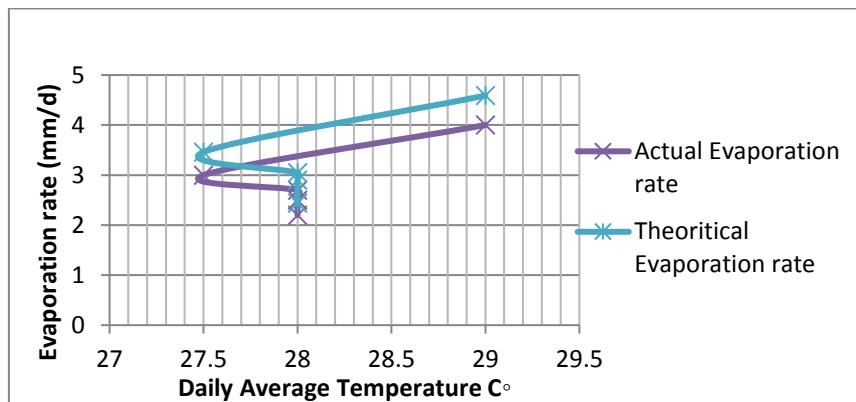


Chart 5.9 : Actual and theoretical evaporation rate at different five daily average ambient air temperature °C in case of using one mirror.

#### - Third scenario: Solar pond using two reflector mirrors:

Chart 5.10 shows the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 12 to 16 July 2015 using two reflector mirrors in solar pond. By comparing between experimental and theoretical values using two reflector mirrors, there were little differences of evaporation rates (mm/d) about 0.35, 0.34, 0.12, 0.2 and 0.14, respectively.

It is noted that the actual rate of evaporation rate using two mirrors increases than the theoretical evaporation rate.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient r value is 0.996.

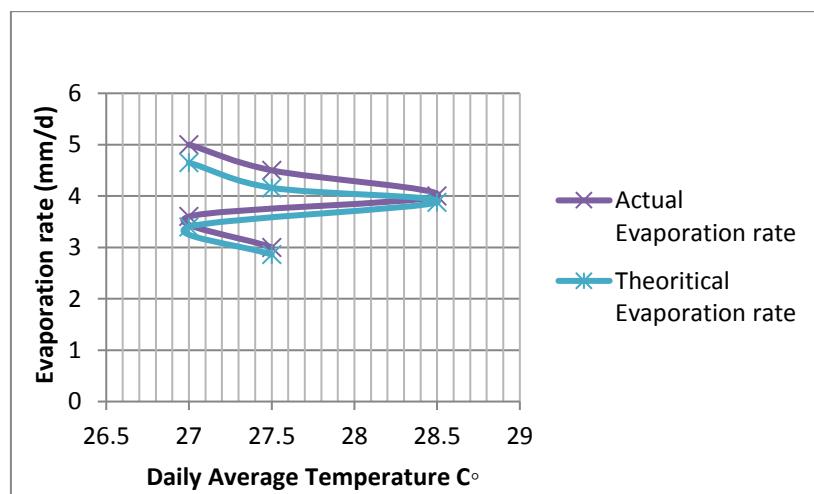


Chart 5.10 : Actual and theoretical Evaporation rate at different five daily average ambient air temperature °C in case of using two mirrors.

### 5.2.1.3.1 Effect of ambient air temperature at different angles on evaporation rate:

- **First scenario: Solar pond using one reflector mirror:**

Chart 5.11 shows the effect of ambient air temperature on evaporation rate using one reflector mirror in solar pond when angle  $\beta$  is changeable. It is clearly seen that increasing of evaporation rate was gradually increased as the ambient air temperature increased. It can be seen from Chart 5.11 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal.

To get accurate mathematical expression of the relation between solar radiation and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (One mirror) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for daily average ambient air temperature model using one mirror shown in table 5.10. The coefficient of determination  $R^2$  represents that the data is very closest to the line of best fit.

$\beta_2$	Resulted equations	Coefficient of determination, $R^2$
35°	$E(\text{mm/d}) = 0.7493T^2 - 41.711T + 584.02$	$R^2 = 0.8936$
38°	$E(\text{mm/d}) = 0.7247 T^2 - 40.318 T + 564.17$	$R^2 = 0.9049$
45°	$E(\text{mm/d}) = 0.668 T^2 - 37.118 T + 518.62$	$R^2 = 0.9285$
50°	$E(\text{mm/d}) = 0.6233 T^2 - 34.594 T + 482.74$	$R^2 = 0.946$
55°	$E(\text{mm/d}) = 0.588 T^2 - 32.599 T + 454.35$	$R^2 = 0.9551$

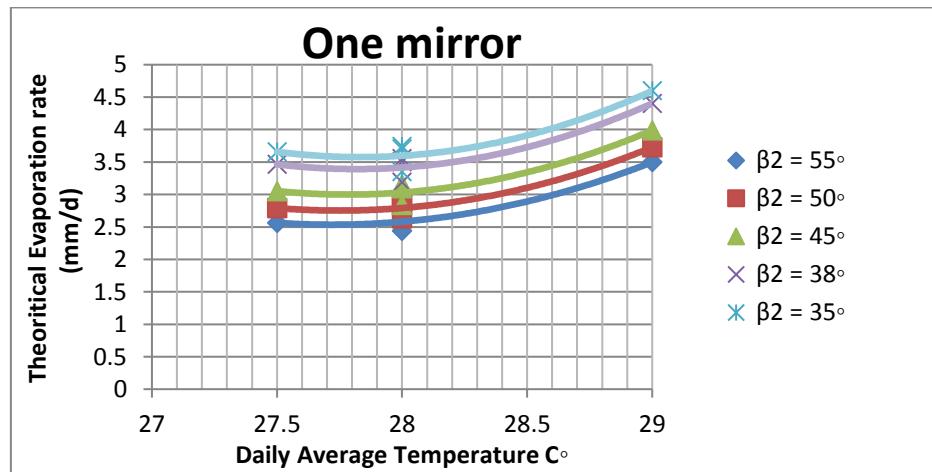


Chart 5.11 : Effect of ambient air temperature on evaporation rate using one reflector mirror in solar pond.

- **Second scenario: Solar pond using two reflector mirrors:**

Chart 5.12 shows the effect of ambient air temperature on evaporation rate using two

reflector mirrors in solar pond when angle  $\beta$  is changeable. Slight increasing of evaporation rate was observed by increasing ambient air temperature because the differences of ambient air temperature were very low and there range was from 27 °C to 28.5 °C It can be seen from chart 5.12 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal.

To get accurate mathematical expression of the relation between ambient air temperature and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (Two mirrors) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for daily average ambient air temperature regression model using two mirrors are shown in table 5.11. The coefficient of determination  $R^2$  represents that the data is little correlation to the line of best fit.

$\beta_1 = \beta_2$	Resulted equations	Coefficient of determination, $R^2$
35°	$E(\text{mm/d}) = -0.0317 T^2 + 1.7328T - 19.71$	$R^2 = 0.0015$
38°	$E(\text{mm/d}) = 0.13 T^2 - 7.3 T + 106.39$	$R^2 = 0.0205$
45°	$E(\text{mm/d}) = 0.3867 T^2 - 21.582 T + 304.91$	$R^2 = 0.0797$
50°	$E(\text{mm/d}) = 0.5467 T^2 - 30.51 T + 429.28$	$R^2 = 0.0953$
55°	$E(\text{mm/d}) = 0.6123 T^2 - 34.127 T + 478.98$	$R^2 = 0.0639$

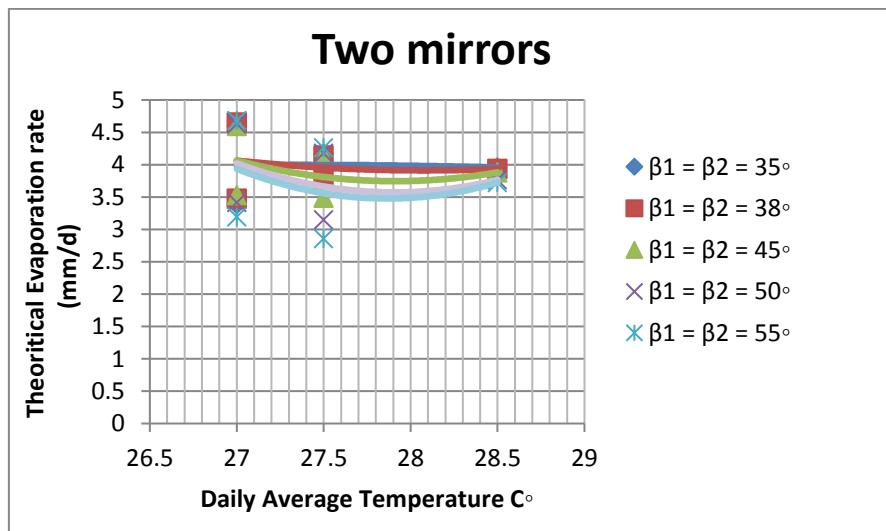


Chart 5.12 : Effect of ambient air temperature on evaporation rate using two reflector mirrors in solar pond.

Finally, charts 5.11 and 5.12 show that when daily average ambient air temperature was 28°C and the mirror's angle makes with horizontal was 55°, 50°, 45°, 38° and 35°, the evaporation rates (mm/d) resulted were 2.57, 2.77, 3.03, 3.43 and 3.56 respectively when using one mirror and 3.47mm, 3.61mm, 3.79mm, 3.91mm and 3.95mm respectively when using two reflector mirrors. This is about 25.87%, 23.18%, 20.03%, 12.26% and 9.92% respectively. Improvement in the efficiency of the solar pond used two reflector mirrors as compared with solar pond used one reflector mirror.

#### 5.2.1.4 Effect of wind speed, Km/hr

The effect of wind speed is given in this section. The effect of wind speed was pronounced on the results of evaporation rates for the three scenarios that are explained next. The results obtained from the model and experiment are discussed and compared with each other.

- **First scenario: Solar pond without using any mirror:**

Table 5.12 shows comparison between actual and theoretical evaporation rate in 17/7/2015 when average wind speed was 9.875 Km/hr in case of without using any mirror. By comparing these values, there is little difference of evaporation rate about 0.1 mm and can be neglected.

Date	Average wind speed Km/hr	Theoretical Evaporation rate (mm/d)	Actual Evaporation rate (mm/d)
17/7/2015	9.875	2.6	2.5

- **Second scenario: Solar pond using one reflector mirror:**

Chart 5.13 shows that the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 18 to 22 July 2015 using one reflector mirror in solar pond. By comparing between experimental and theoretical values using one reflector mirror, there is little difference of evaporation rates (mm/d) about 0.24, 0.4, 0.35, 0.46 and 0.59, respectively.

It is noted that the actual rate of evaporation using one mirror was less than the theoretical evaporation rate.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient  $r$  value is 0.998.

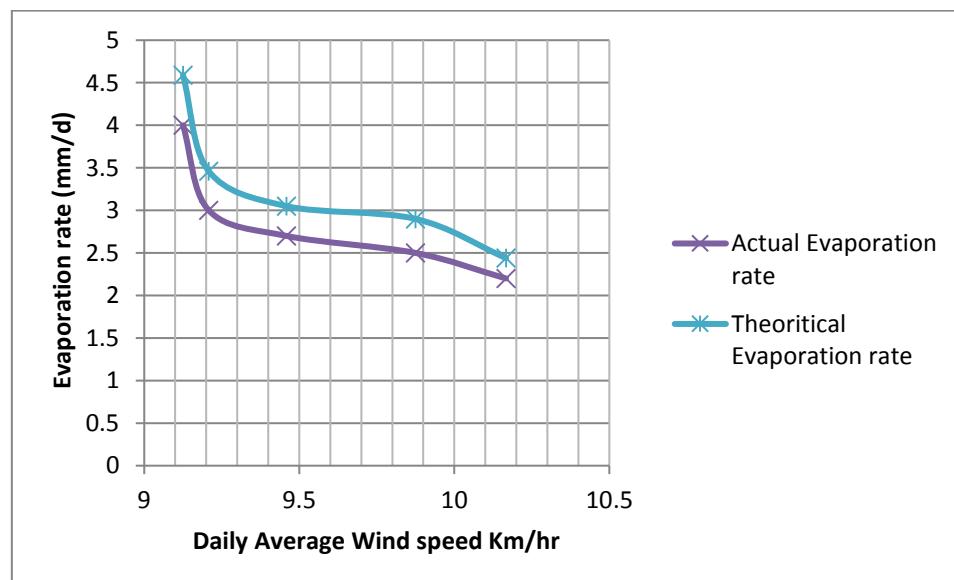


Chart 5.13 : Actual and theoretical evaporation rate at different five daily average wind speed(km/hr) in case of using one mirror.

- **Third scenario: Solar pond using two reflector mirrors:**

Chart 5.14 shows the actual and theoretical evaporation rate resulted from the experiment done during successive five days from 12 to 16 July 2015 using two reflector mirrors in solar pond. By comparing between experimental and theoretical values using two reflector mirrors, there is little difference of evaporation rates (mm/d) about 0.35, 0.34, 0.12, 0.2 and 0.14, respectively.

It is noted that the actual rate of evaporation using two mirrors was increased than the theoretical evaporation rate.

The relationship between the actual and theoretical evaporation rate is generally considered strong since their correlation coefficient  $r$  value was 0.996.

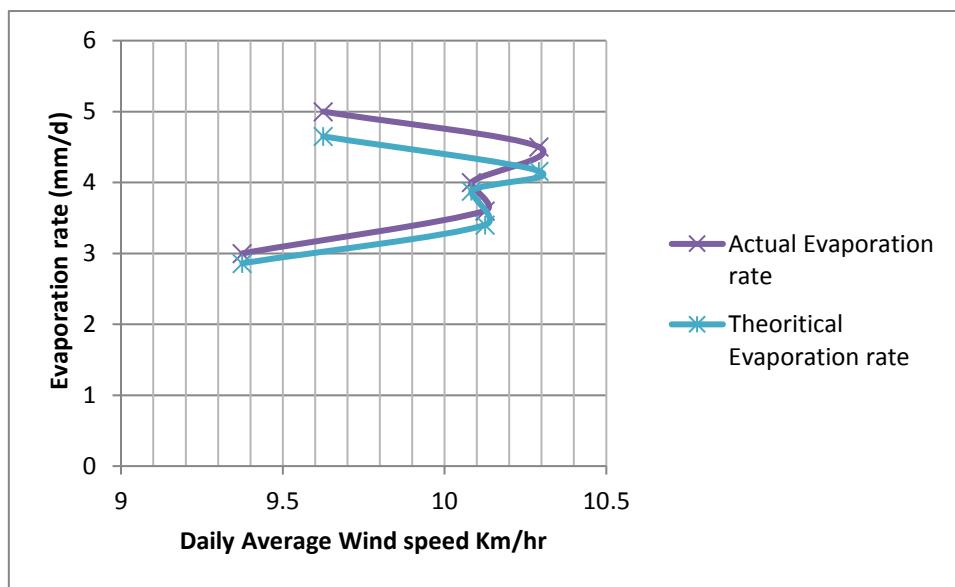


Chart 5.14 : Actual evaporation rate at different five daily average wind speed(km/hr) in case of using two mirrors.

#### **5.2.1.4.1 Effect of daily average wind speed at different angles on evaporation rates:**

- **First scenario: Solar pond using one reflector mirror:**

Chart 5.15 shows the effect of wind speed on evaporation rate using one reflector mirror in solar pond when angle  $\beta$  is changeable. Evaporation rate appears to decrease slightly as wind speed increases. It can be seen from Chart 5.15 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal.

To get accurate mathematical expression of the relation between wind speed and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (One mirror) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for daily average wind speed regression model using one reflector mirror are shown in table 5.13. The coefficient of determination  $R^2$  represents that the data is moderately correlated to the line of best fit.

$\beta_2$	Resulted equations	Coefficient of determination, $R^2$
35°	$E(\text{mm/d}) = 0.8195U^2 - 16.529 U + 86.805$	$R^2 = 0.5262$
38°	$E(\text{mm/d}) = 0.8722 U^2 - 17.52 U + 91.26$	$R^2 = 0.5154$
45°	$E(\text{mm/d}) = 0.9843 U^2 - 19.623 U + 100.71$	$R^2 = 0.4917$
50°	$E(\text{mm/d}) = 1.0772 U^2 - 21.368 U + 108.64$	$R^2 = 0.4727$
55°	$E(\text{mm/d}) = 1.1146 U^2 - 22.059 U + 111.61$	$R^2 = 0.4597$

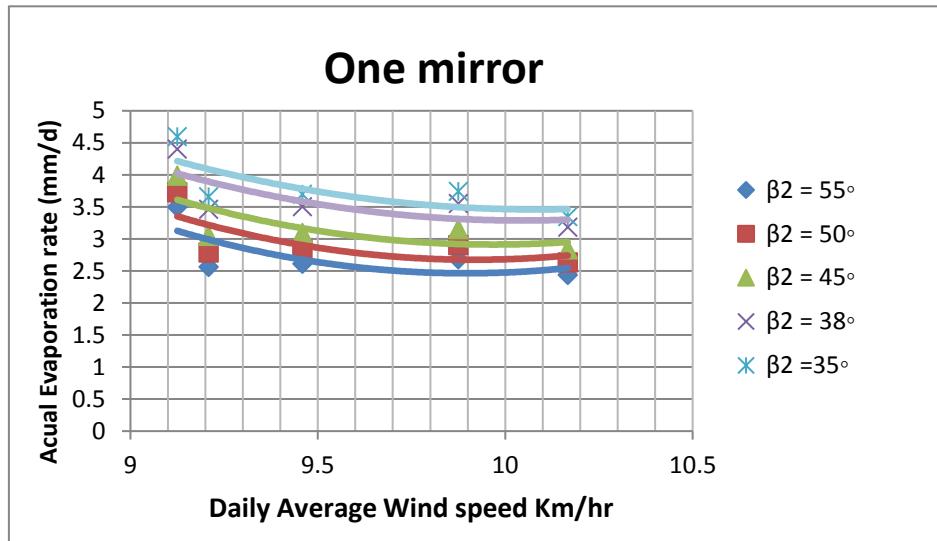


Chart 5.15 : Effect of wind speed on evaporation rate using one reflector mirror in solar pond.

#### - Second scenario: Solar pond using two reflector mirrors:

Chart 5.16 shows the effect of wind speed on evaporation rate using two reflector mirrors in solar pond when angle  $\beta$  is changeable. Little of decreasing evaporation rate was observed by increasing wind speed. It can be seen from chart 5.16 that evaporation rate increases with decreasing the mirror's angle that makes with horizontal.

To get accurate mathematical expression of the relation between wind speed and evaporation rate, five equations were developed to best fit for all groups of data of the tested scenario (Two mirrors) for five different values of  $\beta$  utilizing the Excel software program.

The resulted equations for daily average wind speed regression model using two mirrors shown in table 5.14. The coefficient of determination  $R^2$  represents that the data is little correlation to the line of best fit.

$B1=\beta_2$	Resulted equations	Coefficient of determination, $R^2$
35°	$E(\text{mm/d}) = -0.9372U^2 + 18.155 U - 83.785$	$R^2 = 0.0805$
38°	$E(\text{mm/d}) = -1.4318 U^2 + 27.911 U - 131.82$	$R^2 = 0.1089$
45°	$E(\text{mm/d}) = -2.1022 U^2 + 41.356 U - 199.21$	$R^2 = 0.1398$

50°	$E(\text{mm/d}) = -2.659 U^2 + 52.538 U - 255.38$	$R^2 = 0.1685$
55°	$E(\text{mm/d}) = -3.0246 U^2 + 59.919 U - 292.66$	$R^2 = 0.1696$

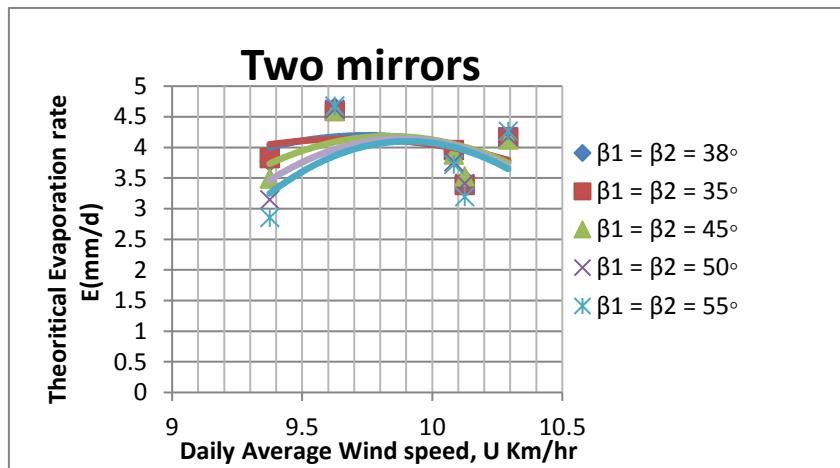


Chart 5.16 : Effect of wind speed on evaporation rate using two reflector mirrors in solar pond.

Charts 5.15 and 5.16 show that when daily average wind speed was 9.5km/hr and the mirror's angles makes with horizontal were 55°, 50°,45°,38° and 35° , the evaporation rates (mm/d) resulted were 2.64, 2.86, 3.12, 3.54 and 3.77 when using one mirror and 3.6mm, 3.76mm ,3.94mm, 4.11 and 4.1mm respectively when using two reflector mirrors. This is about 26.6%,23.83%,20.86%,14.06% and 8.25% respectively, improvement in the efficiency of the solar pond used two reflector mirrors as compared with solar pond used one reflector mirror.

### 5.2.2 Effect of the reflector mirrors on evaporation rate

#### 5.2.2.1 The Effect of the reflectors positions:

To see the effect of the reflectors depending on their positions, simulations have been carried out in five different angles  $\beta$ . The angle between the horizontal axes and RHS reflector  $\beta_2$  was kept at 35°, 38°,45°,50° and 55° using one reflector mirror.

When using two reflector mirrors ,mirror 1 (LHS reflector) and mirror 2 (RHS reflector) make  $\beta_1$  and  $\beta_2$  angles with horizontal, respectively ,the angle between the horizontal axes and LHS reflector was kept at 35°, 38°,45°,50° and 55° and the same angles for RHS reflector.

Charts 5.3, 5.4, 5.7, 5.8, 5.11, 5.12, 5.15 and 5.16 show that evaporation rate increases with decreasing the mirror's angle that makes with horizontal  $\beta$ .

#### 5.2.2.2 The Effect of the reflectors dimensions:

To see the effect of the reflectors depending on their dimensions, the lengths of the reflector mirror we changed for different values and substituted in equations 3.54 and 3.55.

The data in Table 5.15 and 5.16 indicated that evaporation rate did not change when

dimensions of the reflector mirrors have changed.

Table 5.15: Effect of reflector mirror dimensions on evaporation rate using one mirror

One mirror (RHS)								
Angle of mirror, $\beta$	Rs, MJ /m <sup>2</sup> /d	%RH	T, °C	U, Km/hr	Date	Evaporation rate (mm/d)		
						$a = 1m$	$a = 2m$	$a = 4m$
$\beta_2 = 35^\circ$	10.47	68.83	28	10.17	18/07/15	3.34	3.34	3.34
	10.45	67.42	28	9.88	19/07/15	3.74	3.74	3.74
	10.44	68.38	28	9.46	20/07/15	3.69	3.69	3.69
	10.42	66.63	27.5	9.21	21/07/15	3.65	3.65	3.65
	10.40	67.46	29	9.13	22/07/15	4.59	4.59	4.59
$\beta_2 = 38^\circ$	10.47	68.83	28	10.17	18/07/15	3.18	3.18	3.18
	10.45	67.42	28	9.88	19/07/15	3.55	3.55	3.55
	10.44	68.38	28	9.46	20/07/15	3.5	3.5	3.5
	10.42	66.63	27.5	9.21	21/07/15	3.46	3.46	3.46
	10.40	67.46	29	9.13	22/07/15	4.4	4.4	4.4
$\beta_2 = 45^\circ$	10.47	68.83	28	10.17	18/07/15	2.84	2.84	2.84
	10.45	67.42	28	9.88	19/07/15	3.15	3.15	3.15
	10.44	68.38	28	9.46	20/07/15	3.09	3.09	3.09
	10.42	66.63	27.5	9.21	21/07/15	3.05	3.05	3.05
	10.40	67.46	29	9.13	22/07/15	3.98	3.98	3.98
$\beta_2 = 50^\circ$	10.47	68.83	28	10.17	18/07/15	2.63	2.63	2.63
	10.45	67.42	28	9.88	19/07/15	2.9	2.9	2.9
	10.44	68.38	28	9.46	20/07/15	2.84	2.84	2.84
	10.42	66.63	27.5	9.21	21/07/15	2.79	2.79	2.79
	10.40	67.46	29	9.13	22/07/15	3.73	3.73	3.73
$\beta_2 = 55^\circ$	10.47	68.83	28	10.17	18/07/15	2.44	2.44	2.44
	10.45	67.42	28	9.88	19/07/15	2.68	2.68	2.68
	10.44	68.38	28	9.46	20/07/15	2.62	2.62	2.62
	10.42	66.63	27.5	9.21	21/07/15	2.56	2.56	2.56
	10.40	67.46	29	9.13	22/07/15	3.49	3.49	3.49

Table 5.16: Effect of reflector mirrors dimensions on evaporation rate using two mirrors

Two mirrors (RHS and LHS)								
Angle of mirror, $\beta$	Rs, MJ /m <sup>2</sup> /d	%RH	T, °C	U, Km/hr	Date	Evaporation rate (mm/d)		
						$a = 1m$	$a = 2m$	$a = 4m$
$\beta_1 = \beta_2 = 35^\circ$	10.57	61.42	27.00	9.63	12/07/15	4.59	4.59	4.59
	10.56	60.79	27.50	10.29	13/07/15	4.16	4.16	4.16

	10.54	65.04	28.50	10.08	14/07/15	3.95	3.95	3.95	3.95
	10.52	70.21	27.00	10.13	15/07/15	3.38	3.38	3.38	3.38
	10.51	65.92	27.50	9.38	16/07/15	3.83	3.82	3.82	3.82
$\beta_1 = \beta_2 = 38^\circ$	10.57	61.42	27.00	9.63	12/07/15	4.65	4.65	4.65	4.65
	10.56	60.79	27.50	10.29	13/07/15	4.14	4.14	4.14	4.14
	10.54	65.04	28.50	10.08	14/07/15	3.93	3.93	3.93	3.93
	10.52	70.21	27.00	10.13	15/07/15	3.47	3.47	3.47	3.47
	10.51	65.92	27.50	9.38	16/07/15	3.77	3.77	3.77	3.77
$\beta_1 = \beta_2 = 45^\circ$	10.57	61.42	27.00	9.63	12/07/15	4.6	4.6	4.6	4.6
	10.56	60.79	27.50	10.29	13/07/15	4.13	4.13	4.13	4.13
	10.54	65.04	28.50	10.08	14/07/15	3.88	3.88	3.88	3.88
	10.52	70.21	27.00	10.13	15/07/15	3.53	3.53	3.53	3.53
	10.51	65.92	27.50	9.38	16/07/15	3.49	3.49	3.49	3.49
$\beta_1 = \beta_2 = 50^\circ$	10.57	61.42	27.00	9.63	12/07/15	4.63	4.63	4.63	4.63
	10.56	60.79	27.50	10.29	13/07/15	4.18	4.18	4.18	4.18
	10.54	65.04	28.50	10.08	14/07/15	3.76	3.76	3.76	3.76
	10.52	70.21	27.00	10.13	15/07/15	3.41	3.41	3.41	3.41
	10.51	65.92	27.50	9.38	16/07/15	3.15	3.15	3.15	3.15
$\beta_1 = \beta_2 = 55^\circ$	10.57	61.42	27.00	9.63	12/07/15	4.68	4.68	4.68	4.68
	10.56	60.79	27.50	10.29	13/07/15	4.26	4.26	4.26	4.26
	10.54	65.04	28.50	10.08	14/07/15	3.72	3.72	3.72	3.72
	10.52	70.21	27.00	10.13	15/07/15	3.19	3.19	3.19	3.19
	10.51	65.92	27.50	9.38	16/07/15	2.85	2.85	2.85	2.85

The concluded regression model equations of brine evaporation are shown as follows in table 5.17 and 5.18:

Table 5.17: The concluded regression equations for brine evaporation using one mirror

One mirror						
Angle $\beta$	Parameters	Estimate	Standard error	$R^2$	Residuals	Intercept
$\beta_2 = 35^\circ$	U	-1.13846	0	1	0	-179.607
	T	0.908896				
	%RH	-0.24522				
	Rs	17.76127				
	$E(\text{mm/d}) = 17.76\text{Rs} - 0.245(\%RH) + 0.91T - 1.14U - 179.607$					
$\beta_2 = 38^\circ$	U	-0.928	0	1	0	-139.775
	T	0.860304				
	%RH	-0.22247				
	Rs	13.71736				
	$E(\text{mm/d}) = 13.72\text{Rs} - 0.222(\%RH) + 0.86T - 0.928U - 139.775$					
$\beta_2 = 45^\circ$	U	-0.5127	0	1	0	-65.0362
	T	0.764461				
	%RH	-0.18134				

	Rs	6.128827				
$E(\text{mm/d}) = 6.13\text{Rs} - 0.181(\%RH) + 0.764T - 0.513U - 65.0362$						
$\beta_2 = 50^\circ$	U	-0.27107	0	1	0	-21.1513
	T	0.715664				
	%RH	-0.15283				
	Rs	1.625545				
$E(\text{mm/d}) = 1.626\text{Rs} - 0.153(\%RH) + 0.716T - 0.27U - 21.1513$						
$\beta_2 = 55^\circ$	U	-0.13858	0	1	0	0.755127
	T	0.679059				
	%RH	-0.13376				
	Rs	-0.64117				
$E(\text{mm/d}) = -0.641\text{Rs} - 0.134(\%RH) + 0.679T - 0.138U + 0.75513$						

Table 5.18: The concluded regression equations for brine evaporation using two mirrors

Two mirrors						
Angle $\beta$	Parameters	Estimate	Standard error	$R^2$	Residuals	Intercept
$\beta_1 = \beta_2 = 35^\circ$	U	-0.51559	0	1	0	-115.236
	T	0.060771				
	%RH	-0.04607				
	Rs	11.91926				
	$E(\text{mm/d}) = 11.92\text{Rs} - 0.046(\%RH) + 0.061T - 0.516U - 115.236$					
$\beta_1 = \beta_2 = 38^\circ$	U	-0.5246	0	1	0	-150.069
	T	0.01953				
	%RH	-0.02496				
	Rs	15.21147				
	$E(\text{mm/d}) = 15.21\text{Rs} - 0.025(\%RH) + 0.019T - 0.525U - 150.069$					
$\beta_1 = \beta_2 = 45^\circ$	U	-0.32797	0	1	0	-201.731
	T	-0.01718				
	%RH	0.000645				
	Rs	19.8606				
	$E(\text{mm/d}) = 19.86\text{Rs} + 0.00064(\%RH) - 0.017T - 0.328U - 201.731$					
$\beta_1 = \beta_2 = 50^\circ$	U	-0.16342	0	1	0	-254.51
	T	-0.07504				
	%RH	0.000313				
	Rs	24.85698				
	$E(\text{mm/d}) = 24.857\text{Rs} + 0.00031(\%RH) - 0.075T - 0.163U - 254.51$					
$\beta_1 = \beta_2 = 55^\circ$	U	-0.06071	0	1	0	-305.506
	T	-0.05097				
	%RH	-0.01147				
	Rs	29.60008				
	$E(\text{mm/d}) = 29.6\text{Rs} - 0.01147(\%RH) - 0.051T - 0.061U - 305.506$					

Where:

$E$  = the evaporation rate expressed as mm/day,

$R_s$ = the solar radiation ( $\text{MJ m}^{-2}\text{day}^{-1}$ ),

$\text{RH}$  = the relative humidity (%),

$T$  = the ambient air temperature,  $^{\circ}\text{C}$ ,

$U$  = Wind speed, Km/hr.

The previous models have shown the importance of the variables as the global solar radiation, relative humidity, ambient air temperature and wind speed. It assumed that secondary variables had been neglected, the coefficient of determination  $R^2$  for the final models was 100% .

Tables 5.17 and 5.18 show that when solar radiation was  $10.99 \text{ MJ/m}^2/\text{d}$ , daily average humidity was 66% , average ambient air temperature was  $28^{\circ}\text{C}$  and daily average wind speed was 9.5km/hr, the mirror's angle makes with horizontal was  $55^{\circ}$ ,  $50^{\circ}$ , $45^{\circ}$ , $38^{\circ}$  and  $35^{\circ}$ , the evaporation rate resulted was 2.56mm, 4.1mm ,6.9mm, 11.62mm and 14.06mm respectively when using one mirror and 17.03 mm, 15mm, 12.98mm, 10.98mm and 9.5mm respectively when using two reflector mirrors. This is about 84.93%,72.72%,46.81% and 30.7% improvement in the efficiency of the solar pond used two reflector mirrors as compared with solar pond used one reflector mirror when  $\beta$  was  $55^{\circ}$ , $50^{\circ}$  and  $45^{\circ}$  respectively. There is performance deficiency about 5.47% and 32.16% of the solar pond used two reflector mirrors as compared with solar pond used one reflector mirror when  $\beta$  was  $38^{\circ}$ , $50^{\circ}$  and  $35^{\circ}$  respectively.

This means that reflectors play a vital role on the performance of solar ponds contributing to harvesting much more solar energy and increasing the energy harvesting area.

Table 5.19: The increased efficiency in evaporation rate using one mirror and two mirrors and comparing it in case of without using any mirror

Evaporation rate (mm/day)			
Mirror Angle	One mirror	Two mirrors	The increased efficiency %
$\beta = 35^{\circ}$	4	4.5	11.11
$\beta = 38^{\circ}$	3	5	40
$\beta = 45^{\circ}$	2.7	4	32.5
$\beta = 50^{\circ}$	2.5	3.6	30.6
$\beta = 55^{\circ}$	2.2	3	26.7

Evaporation rate (mm/day)		
Without mirror	One mirror	The increased efficiency %
2.5	4	37.5
2.5	3	14.3
2.5	2.7	7.4

Evaporation rate (mm/day)		
Without mirror	Two mirrors	The increased efficiency %
2.5	4.5	44.44
2.5	5	50
2.5	4	37.5

2.5	3.6	30.6
2.5	3	16.7

Table 5.20: Percent reduce in solar pond area using one mirror and two mirrors:

Evaporation rate (mm/day)			
Mirror Angle	One mirror	Two mirrors	Percent reduce in solar pond area %
$\beta = 35^\circ$	4	4.5	88.89
$\beta = 38^\circ$	3	5	60
$\beta = 45^\circ$	2.7	4	67.5
$\beta = 50^\circ$	2.5	3.6	69.4
$\beta = 55^\circ$	2.2	3	73.3

Evaporation rate (mm/day)		
Without mirror	One mirror	Percent reduce in solar pond area %
2.5	4	62.5
2.5	3	83.33
2.5	2.7	92.6

Evaporation rate (mm/day)		
Without mirror	Two mirrors	Percent reduce in solar pond area %
2.5	4.5	55.6
2.5	5	50
2.5	4	62.5
2.5	3.6	69.44
2.5	3	83.33

## **Chapter 6: Conclusions and Recommendations**

### **6.1 Conclusions:**

In this research the brine characteristics were studied by using shallow solar pond SSP. The main input parameters for three different scenarios (solar pond without mirror, solar pond using one mirror and solar pond using two mirrors) where solar radiation, ambient air temperature, relative humidity and wind speed were used as variables. The method described herein cover one technique for evaporating brine is solar evaporation that does not require fuel but may take days or weeks to accomplish and is limited to geographic areas with high evaporation and little precipitation. At the end of the experiments the following important conclusions were drawn:-

- 1 - Little of increasing of the evaporation rate was observed until it reach the maximum at relative humidity of 67.6%. After that, evaporation rates shows a slight decrease with increasing of relative humidity when using one reflector mirror.
- 2 - Evaporation rate increases with decreasing the mirror's angle that makes with horizontal.
- 3 - Little of decreasing the evaporation rate was observed by increasing relative humidity.
- 4 - Increasing of evaporation rate was gradually increased as the ambient air temperature increased using one reflector mirror(RHS).
- 5 - Slight increasing of evaporation rate was observed by increasing ambient air temperature using two reflector mirrors(RHS and LHS).
- 6 - Evaporation rate appears to decrease slightly as wind speed increases using one reflector mirror(RHS).
- 7 - Little of decreasing evaporation rate was observed by increasing wind speed using two reflector mirrors(RHS and LHS).
- 8 - Little of decreasing the evaporation rate with increasing of solar radiation using one reflector mirror(RHS).
- 9 - Gradual increasing of evaporation rate with increasing solar radiation using two reflector mirrors.
- 10 - Reflectors play a vital role on the performance of solar ponds contributing to harvesting much more solar energy and increasing the energy harvesting area.

11 - Experimental and theoretical model results, obtained for the solar pond without a mirror, with one reflector mirror and with two reflector mirrors are in a good agreement with each other.

12 - Mirrors are very effective when they are used as reflectors and that the best performance of the pond can be achieved when the mirrors are employed as reflectors.

13 - Using one mirror and two mirrors reduced the solar pond area and hence reduced area needed for brine evaporation in Gaza strip desalination plants.

## **6.2 Recommendations:**

1 - It is recommended that further research by using distinct techniques for evaporating brine other than solar evaporation such as boiling due to an externally applied heat source, and boiling caused by a hot immersed object.

2 - It is recommended for further research to study the thermal performance of a laboratory model shallow solar evaporation pond with the objective of making salt and purify water from the brine solution.

3 - It is recommended for further research to study brine evaporation in large scale of solar pond area using reflector mirrors.

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## Appendix (A)

Table A:1 Calculation Results Sheet No. 1 of Appendix A

Calculation for Experiment No.1 (12/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg /l)	m (mo les/l )	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	e <sub>s</sub>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	12	193	25	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	74
2	1:00 AM	12	193	22	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	82
3	2:00 AM	12	193	23	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	80
4	3:00 AM	12	193	23	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	74
5	4:00 AM	12	193	22	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	72
6	5:00 AM	12	193	23	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	72
7	6:00 AM	12	193	23	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	71
8	7:00 AM	12	193	24	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	67
9	8:00 AM	12	193	25	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	70
10	9:00 AM	12	193	26	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	64
11	10:00 AM	12	193	27	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	56
12	11:00 AM	12	193	28	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	101	0.066155	50
13	12:00 PM	12	193	29	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	45
14	1:00 PM	12	193	29	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	46
15	2:00 PM	12	193	30	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	48
16	3:00 PM	12	193	31	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	46
17	4:00 PM	12	193	32	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	44
18	5:00 PM	12	193	32	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	43
19	6:00 PM	12	193	31	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	45
20	7:00 PM	12	193	29	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	56
21	8:00 PM	12	193	28	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	63
22	9:00 PM	12	193	28	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	66
23	10:00 PM	12	193	26	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	69
24	11:00 PM	12	193	25	2.44	73222	1.25	0.96	2.53	4.56	3.55	0.21	100.8	0.066024	71

Table A:2 Calculation Results Sheet No. 2 of Appendix A

Calculation for Experiment No.2 (13/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg /l)	m (mo les/l )	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	e <sub>s</sub>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	13	194	24	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.5	0.065828	68
2	1:00 AM	13	194	24	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.5	0.065828	67
3	2:00 AM	13	194	24	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.5	0.065828	67
4	3:00 AM	13	194	23	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.5	0.065828	64
5	4:00 AM	13	194	22	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.5	0.065828	73
6	5:00 AM	13	194	22	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.5	0.065828	74
7	6:00 AM	13	194	23	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	71
8	7:00 AM	13	194	24	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	66
9	8:00 AM	13	194	25	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	70
10	9:00 AM	13	194	26	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	64
11	10:00 AM	13	194	27	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	59
12	11:00 AM	13	194	29	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	53
13	12:00 PM	13	194	30	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	50
14	1:00 PM	13	194	30	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	51
15	2:00 PM	13	194	30	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	50
16	3:00 PM	13	194	31	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	48
17	4:00 PM	13	194	32	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	45
18	5:00 PM	13	194	33	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	43
19	6:00 PM	13	194	32	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	46
20	7:00 PM	13	194	30	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	53
21	8:00 PM	13	194	29	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	59
22	9:00 PM	13	194	28	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	67
23	10:00 PM	13	194	26	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	73
24	11:00 PM	13	194	25	2.44	73222	1.25	0.96	2.53	4.82	3.68	0.21	100.6	0.065893	78

Table A:3 Calculation Results Sheet No. 3 of Appendix A

Calculation for Experiment No.3 (14/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg /l)	m (mo les/l )	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	e <sub>s</sub>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	14	195	25	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	78
2	1:00 AM	14	195	24	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	78
3	2:00 AM	14	195	24	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	78
4	3:00 AM	14	195	23	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	70
5	4:00 AM	14	195	23	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	78
6	5:00 AM	14	195	23	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	79
7	6:00 AM	14	195	24	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	76
8	7:00 AM	14	195	25	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	74
9	8:00 AM	14	195	26	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	74
10	9:00 AM	14	195	27	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	70
11	10:00 AM	14	195	28	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	63
12	11:00 AM	14	195	30	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	55
13	12:00 PM	14	195	31	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	49
14	1:00 PM	14	195	31	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	47
15	2:00 PM	14	195	31	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	51
16	3:00 PM	14	195	32	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	48
17	4:00 PM	14	195	33	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	47
18	5:00 PM	14	195	34	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	45
19	6:00 PM	14	195	32	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	54
20	7:00 PM	14	195	30	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	61
21	8:00 PM	14	195	30	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	63
22	9:00 PM	14	195	28	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	69
23	10:00 PM	14	195	27	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	74
24	11:00 PM	14	195	25	2.43	73222	1.25	0.96	2.69	5.10	3.89	0.23	100.6	0.065893	80

Table A:4 Calculation Results Sheet No. 4 of Appendix A

Calculation for Experiment No.4 (15/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg /l)	m (mo les/l )	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	e <sub>s</sub>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	15	196	25	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	79
2	1:00 AM	15	196	25	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	77
3	2:00 AM	15	196	25	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	74
4	3:00 AM	15	196	24	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	75
5	4:00 AM	15	196	24	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	72
6	5:00 AM	15	196	24	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	77
7	6:00 AM	15	196	24	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.90	0.0660895	83
8	7:00 AM	15	196	24	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.90	0.0660895	85
9	8:00 AM	15	196	25	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.90	0.0660895	80
10	9:00 AM	15	196	26	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.90	0.0660895	73
11	10:00 AM	15	196	27	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.90	0.0660895	67
12	11:00 AM	15	196	28	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.90	0.0660895	62
13	12:00 PM	15	196	29	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	59
14	1:00 PM	15	196	30	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	56
15	2:00 PM	15	196	30	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	52
16	3:00 PM	15	196	30	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	54
17	4:00 PM	15	196	30	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	55
18	5:00 PM	15	196	29	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	58
19	6:00 PM	15	196	28	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	64
20	7:00 PM	15	196	27	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	69
21	8:00 PM	15	196	26	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	77
22	9:00 PM	15	196	26	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	77
23	10:00 PM	15	196	26	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	80
24	11:00 PM	15	196	25	2.44	73222	1.25	0.96	2.86	4.07	3.46	0.20	100.80	0.066024	80

Table A:5 Calculation Results Sheet No. 5 of Appendix A

Calculation for Experiment No.5 (16/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg/l)	m (moles/l)	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	<i>e<sub>S</sub></i>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	16	197	24	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	82.00
2	1:00 AM	16	197	24	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	82.00
3	2:00 AM	16	197	24	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	79.00
4	3:00 AM	16	197	23	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	85.00
5	4:00 AM	16	197	21	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	90.00
6	5:00 AM	16	197	21	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	87.00
7	6:00 AM	16	197	21	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.90	0.0660895	83.00
8	7:00 AM	16	197	23	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.90	0.0660895	83.00
9	8:00 AM	16	197	25	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.90	0.0660895	74.00
10	9:00 AM	16	197	26	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.90	0.0660895	68.00
11	10:00 AM	16	197	29	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.90	0.0660895	57.00
12	11:00 AM	16	197	31	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.90	0.0660895	50.00
13	12:00 PM	16	197	32	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	46.00
14	1:00 PM	16	197	32	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	43.00
15	2:00 PM	16	197	32	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	45.00
16	3:00 PM	16	197	33	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	44.00
17	4:00 PM	16	197	34	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	42.00
18	5:00 PM	16	197	33	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	45.00
19	6:00 PM	16	197	32	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	50.00
20	7:00 PM	16	197	32	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	55.00
21	8:00 PM	16	197	30	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	63.00
22	9:00 PM	16	197	29	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	71.00
23	10:00 PM	16	197	27	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	77.00
24	11:00 PM	16	197	25	2.44	73222	1.25	0.96	2.38	5.10	3.74	0.22	100.80	0.066024	81.00

Table A:6 Calculation Results Sheet No. 6 of Appendix A

Calculation for Experiment No.6 (17/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg/l)	m (moles/l)	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	<i>e<sub>S</sub></i>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	17	198	24	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	80
2	1:00 AM	17	198	24	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	79
3	2:00 AM	17	198	24	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	71
4	3:00 AM	17	198	22	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	75
5	4:00 AM	17	198	22	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	73
6	5:00 AM	17	198	22	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	72
7	6:00 AM	17	198	22	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	67
8	7:00 AM	17	198	23	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	64
9	8:00 AM	17	198	25	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	55
10	9:00 AM	17	198	27	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	49
11	10:00 AM	17	198	29	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	46
12	11:00 AM	17	198	30	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	46
13	12:00 PM	17	198	31	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	48
14	1:00 PM	17	198	31	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	49
15	2:00 PM	17	198	31	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	47
16	3:00 PM	17	198	33	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	43
17	4:00 PM	17	198	33	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	44
18	5:00 PM	17	198	34	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	44
19	6:00 PM	17	198	32	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	50
20	7:00 PM	17	198	32	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	55
21	8:00 PM	17	198	30	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	66
22	9:00 PM	17	198	28	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	73
23	10:00 PM	17	198	27	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	79
24	11:00 PM	17	198	25	2.43	160774	2.75	0.90	2.39	4.81	3.60	0.21	100.80	0.066024	84

Table A:7 Calculation Results Sheet No. 7 of Appendix A

Calculation for Experiment No.7 (18/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg/l)	m (moles/l)	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	<i>e<sub>S</sub></i>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	18	199	24	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	84
2	1:00 AM	18	199	25	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	80
3	2:00 AM	18	199	25	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	77
4	3:00 AM	18	199	25	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	76
5	4:00 AM	18	199	25	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	76
6	5:00 AM	18	199	24	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	78
7	6:00 AM	18	199	25	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	77
8	7:00 AM	18	199	25	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	82
9	8:00 AM	18	199	26	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	76
10	9:00 AM	18	199	28	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	69
11	10:00 AM	18	199	29	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	63
12	11:00 AM	18	199	30	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	58
13	12:00 PM	18	199	31	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	55
14	1:00 PM	18	199	31	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	53
15	2:00 PM	18	199	31	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	52
16	3:00 PM	18	199	32	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	51
17	4:00 PM	18	199	31	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	55
18	5:00 PM	18	199	30	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	58
19	6:00 PM	18	199	30	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	59
20	7:00 PM	18	199	29	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	64
21	8:00 PM	18	199	28	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	70
22	9:00 PM	18	199	27	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	77
23	10:00 PM	18	199	26	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	81
24	11:00 PM	18	199	26	2.43	160774	2.75	0.90	2.70	4.30	3.50	0.20	100.7	0.0659585	81

Table A:8 Calculation Results Sheet No. 8 of Appendix A

Calculation for Experiment No.8 (19/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg/l)	m (moles/l)	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	<i>e<sub>S</sub></i>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	19	200	25	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	81
2	1:00 AM	19	200	25	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	77
3	2:00 AM	19	200	26	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	70
4	3:00 AM	19	200	24	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	85
5	4:00 AM	19	200	23	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	89
6	5:00 AM	19	200	23	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	88
7	6:00 AM	19	200	24	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	83
8	7:00 AM	19	200	24	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	80
9	8:00 AM	19	200	26	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	77
10	9:00 AM	19	200	27	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	71
11	10:00 AM	19	200	29	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	61
12	11:00 AM	19	200	30	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	56
13	12:00 PM	19	200	31	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	52
14	1:00 PM	19	200	31	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	50
15	2:00 PM	19	200	31	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	48
16	3:00 PM	19	200	32	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	45
17	4:00 PM	19	200	33	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	44
18	5:00 PM	19	200	32	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	49
19	6:00 PM	19	200	32	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	55
20	7:00 PM	19	200	31	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	61
21	8:00 PM	19	200	30	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	66
22	9:00 PM	19	200	28	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	72
23	10:00 PM	19	200	27	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	77
24	11:00 PM	19	200	25	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	81

Table A:9 Calculation Results Sheet No. 9 of Appendix A

Calculation for Experiment No.9 (20/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg/l)	m (moles/l)	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	e <sub>s</sub>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	20	201	24	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	82
2	1:00 AM	20	201	24	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	82
3	2:00 AM	20	201	23	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	82
4	3:00 AM	20	201	23	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	81
5	4:00 AM	20	201	23	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	90
6	5:00 AM	20	201	23	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	93
7	6:00 AM	20	201	23	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	92
8	7:00 AM	20	201	24	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	86
9	8:00 AM	20	201	26	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	80
10	9:00 AM	20	201	27	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	73
11	10:00 AM	20	201	29	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	60
12	11:00 AM	20	201	30	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	50
13	12:00 PM	20	201	31	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	44
14	1:00 PM	20	201	31	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	41
15	2:00 PM	20	201	32	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	40
16	3:00 PM	20	201	32	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	45
17	4:00 PM	20	201	33	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	44
18	5:00 PM	20	201	33	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	48
19	6:00 PM	20	201	32	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	53
20	7:00 PM	20	201	30	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	63
21	8:00 PM	20	201	29	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	71
22	9:00 PM	20	201	27	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	78
23	10:00 PM	20	201	26	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	81
24	11:00 PM	20	201	26	2.43	160774	2.75	0.90	2.54	4.55	3.54	0.21	100.6	0.065893	82

Table A:10 Calculation Results Sheet No. 10 of Appendix A

Calculation for Experiment No.10 (21/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg/l)	m (moles/l)	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	e <sub>s</sub>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	21	202	25	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	82
2	1:00 AM	21	202	24	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	86
3	2:00 AM	21	202	24	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	83
4	3:00 AM	21	202	23	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	79
5	4:00 AM	21	202	22	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	89
6	5:00 AM	21	202	22	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	95
7	6:00 AM	21	202	23	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	89
8	7:00 AM	21	202	24	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	83
9	8:00 AM	21	202	24	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	86
10	9:00 AM	21	202	26	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	77
11	10:00 AM	21	202	30	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	56
12	11:00 AM	21	202	31	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	47
13	12:00 PM	21	202	32	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	40
14	1:00 PM	21	202	32	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	39
15	2:00 PM	21	202	32	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	38
16	3:00 PM	21	202	33	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	38
17	4:00 PM	21	202	33	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	40
18	5:00 PM	21	202	33	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	44
19	6:00 PM	21	202	31	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	51
20	7:00 PM	21	202	31	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	61
21	8:00 PM	21	202	30	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	66
22	9:00 PM	21	202	29	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	71
23	10:00 PM	21	202	28	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	77
24	11:00 PM	21	202	27	2.43	160774	2.75	0.90	2.39	4.55	3.47	0.20	100.6	0.065893	82

Table A:11 Calculation Results Sheet No. 11 of Appendix A

Calculation for Experiment No.11 (22/7/2015)															
No of hours	Time (hours)	Experiment day	J (No. of days)	Tem p.°C	latent heat of eva. λ	m(mg/l)	m (moles/l)	a <sub>w</sub>	e <sub>(T<sub>min</sub>)</sub>	e <sub>(T<sub>max</sub>)</sub>	e <sub>s</sub>	Δ	P(Kpa)	γ	RH%
1	12:00 AM	22	203	24	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	90
2	1:00 AM	22	203	24	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	90
3	2:00 AM	22	203	23	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	89
4	3:00 AM	22	203	23	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	81
5	4:00 AM	22	203	23	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	91
6	5:00 AM	22	203	23	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	96
7	6:00 AM	22	203	24	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	93
8	7:00 AM	22	203	24	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	85
9	8:00 AM	22	203	25	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	81
10	9:00 AM	22	203	27	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	74
11	10:00 AM	22	203	28	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	66
12	11:00 AM	22	203	31	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	54
13	12:00 PM	22	203	32	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	48
14	1:00 PM	22	203	32	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	44
15	2:00 PM	22	203	32	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	42
16	3:00 PM	22	203	34	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	38
17	4:00 PM	22	203	35	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	37
18	5:00 PM	22	203	34	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	41
19	6:00 PM	22	203	34	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	44
20	7:00 PM	22	203	31	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	54
21	8:00 PM	22	203	30	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	63
22	9:00 PM	22	203	29	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	68
23	10:00 PM	22	203	28	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	73
24	11:00 PM	22	203	27	2.43	160774	2.75	0.90	2.54	5.08	3.81	0.22	100.7	0.0659585	77

## Appendix (B)

Table B:1 Calculation Results Sheet No. 1 of Appendix B

Calculation for Experiment No.1 (12/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	Fu	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	11:58 PM
2	1:00 AM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	12:58 AM
3	2:00 AM	2.01847	6	1.67	12.17	0.082	0.97	110.47	15.71	30	-2.13	1:58 AM
4	3:00 AM	2.01847	6	1.67	12.17	0.082	0.97	110.47	15.71	30	-2.13	2:58 AM
5	4:00 AM	2.01847	6	1.67	12.17	0.082	0.97	110.47	15.71	30	-2.13	3:58 AM
6	5:00 AM	2.01847	6	1.67	12.17	0.082	0.97	110.47	15.71	30	-2.13	4:58 AM
7	6:00 AM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	5:58 AM
8	7:00 AM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	6:58 AM
9	8:00 AM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	7:58 AM
10	9:00 AM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	8:58 AM
11	10:00 AM	2.01847	9	2.50	15.05	0.082	0.97	110.47	15.71	30	-2.13	9:58 AM
12	11:00 AM	2.01847	11	3.06	16.96	0.082	0.97	110.47	15.71	30	-2.13	10:58 AM
13	12:00 PM	2.01847	11	3.06	16.96	0.082	0.97	110.47	15.71	30	-2.13	11:58 AM
14	1:00 PM	2.01847	15	4.17	20.79	0.082	0.97	110.47	15.71	30	-2.13	12:58 AM
15	2:00 PM	2.01847	17	4.72	22.71	0.082	0.97	110.47	15.71	30	-2.13	1:58 PM
16	3:00 PM	2.01847	13	3.61	18.88	0.082	0.97	110.47	15.71	30	-2.13	2:58 PM
17	4:00 PM	2.01847	17	4.72	22.71	0.082	0.97	110.47	15.71	30	-2.13	3:58 PM
18	5:00 PM	2.01847	17	4.72	22.71	0.082	0.97	110.47	15.71	30	-2.13	4:58 PM
19	6:00 PM	2.01847	13	3.61	18.88	0.082	0.97	110.47	15.71	30	-2.13	5:58 PM
20	7:00 PM	2.01847	13	3.61	18.88	0.082	0.97	110.47	15.71	30	-2.13	6:58 PM
21	8:00 PM	2.01847	9	2.50	15.05	0.082	0.97	110.47	15.71	30	-2.13	7:58 PM
22	9:00 PM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	8:58 PM
23	10:00 PM	2.01847	7	1.94	13.13	0.082	0.97	110.47	15.71	30	-2.13	9:58 PM
24	11:00 PM	2.01847	6	1.67	12.17	0.082	0.97	110.47	15.71	30	-2.13	10:58 PM

Table B:2 Calculation Results Sheet No. 2 of Appendix B

Calculation for Experiment No.2 (13/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.024533	6	1.67	12.17	0.082	0.97	111.45	3.52	30	-14.32	11:46 PM
2	1:00 AM	2.024533	9	2.50	15.05	0.082	0.97	111.45	3.52	30	-14.32	12:46 AM
3	2:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	1:46 AM
4	3:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	2:46 AM
5	4:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	3:46 AM
6	5:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	4:46 AM
7	6:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	5:46 AM
8	7:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	6:46 AM
9	8:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	7:46 AM
10	9:00 AM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	8:46 AM
11	10:00 AM	2.024533	9	2.50	15.05	0.082	0.97	111.45	3.52	30	-14.32	9:46 AM
12	11:00 AM	2.024533	11	3.06	16.96	0.082	0.97	111.45	3.52	30	-14.32	10:46 AM
13	12:00 PM	2.024533	11	3.06	16.96	0.082	0.97	111.45	3.52	30	-14.32	11:46 AM
14	1:00 PM	2.024533	15	4.17	20.79	0.082	0.97	111.45	3.52	30	-14.32	12:46 AM
15	2:00 PM	2.024533	17	4.72	22.71	0.082	0.97	111.45	3.52	30	-14.32	1:46 PM
16	3:00 PM	2.024533	13	3.61	18.88	0.082	0.97	111.45	3.52	30	-14.32	2:46 PM
17	4:00 PM	2.024533	17	4.72	22.71	0.082	0.97	111.45	3.52	30	-14.32	3:46 PM
18	5:00 PM	2.024533	15	4.17	20.79	0.082	0.97	111.45	3.52	30	-14.32	4:46 PM
19	6:00 PM	2.024533	13	3.61	18.88	0.082	0.97	111.45	3.52	30	-14.32	5:46 PM
20	7:00 PM	2.024533	15	4.17	20.79	0.082	0.97	111.45	3.52	30	-14.32	6:46 PM
21	8:00 PM	2.024533	13	3.61	18.88	0.082	0.97	111.45	3.52	30	-14.32	7:46 PM
22	9:00 PM	2.024533	11	3.06	16.96	0.082	0.97	111.45	3.52	30	-14.32	8:46 PM
23	10:00 PM	2.024533	9	2.50	15.05	0.082	0.97	111.45	3.52	30	-14.32	9:46 PM
24	11:00 PM	2.024533	7	1.94	13.13	0.082	0.97	111.45	3.52	30	-14.32	10:46 PM

Table B:3 Calculation Results Sheet No. 3 of Appendix B

Calculation for Experiment No.3 (14/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	11:28 PM
2	1:00 AM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	12:28 AM
3	2:00 AM	2.22	7	1.94	13.13	0.082	0.97	112.44	-14.59	30	-32.43	1:28 AM
4	3:00 AM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	2:28 AM
5	4:00 AM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	3:28 AM
6	5:00 AM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	4:28 AM
7	6:00 AM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	5:28 AM
8	7:00 AM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	6:28 AM
9	8:00 AM	2.22	4	1.11	10.26	0.082	0.97	112.44	-14.59	30	-32.43	7:28 AM
10	9:00 AM	2.22	4	1.11	10.26	0.082	0.97	112.44	-14.59	30	-32.43	8:28 AM
11	10:00 AM	2.22	7	1.94	13.13	0.082	0.97	112.44	-14.59	30	-32.43	9:28 AM
12	11:00 AM	2.22	11	3.06	16.96	0.082	0.97	112.44	-14.59	30	-32.43	10:28 AM
13	12:00 PM	2.22	13	3.61	18.88	0.082	0.97	112.44	-14.59	30	-32.43	11:28 AM
14	1:00 PM	2.22	17	4.72	22.71	0.082	0.97	112.44	-14.59	30	-32.43	12:28 AM
15	2:00 PM	2.22	17	4.72	22.71	0.082	0.97	112.44	-14.59	30	-32.43	1:28 PM
16	3:00 PM	2.22	15	4.17	20.79	0.082	0.97	112.44	-14.59	30	-32.43	2:28 PM
17	4:00 PM	2.22	18	5.00	23.66	0.082	0.97	112.44	-14.59	30	-32.43	3:28 PM
18	5:00 PM	2.22	18	5.00	23.66	0.082	0.97	112.44	-14.59	30	-32.43	4:28 PM
19	6:00 PM	2.22	15	4.17	20.79	0.082	0.97	112.44	-14.59	30	-32.43	5:28 PM
20	7:00 PM	2.22	15	4.17	20.79	0.082	0.97	112.44	-14.59	30	-32.43	6:28 PM
21	8:00 PM	2.22	13	3.61	18.88	0.082	0.97	112.44	-14.59	30	-32.43	7:28 PM
22	9:00 PM	2.22	11	3.06	16.96	0.082	0.97	112.44	-14.59	30	-32.43	8:28 PM
23	10:00 PM	2.22	9	2.50	15.05	0.082	0.97	112.44	-14.59	30	-32.43	9:28 PM
24	11:00 PM	2.22	6	1.67	12.17	0.082	0.97	112.44	-14.59	30	-32.43	10:28 PM

Table B:4 Calculation Results Sheet No. 4 of Appendix B

Calculation for Experiment No.4 (15/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.27	6.00	1.67	12.17	0.082	0.97	113.42	-1.60	30	-19.44	11:41 PM
2	1:00 AM	2.27	4.00	1.11	10.26	0.082	0.97	113.42	-1.60	30	-19.44	12:41 AM
3	2:00 AM	2.27	4.00	1.11	10.26	0.082	0.97	113.42	-1.60	30	-19.44	1:41 AM
4	3:00 AM	2.27	6.00	1.67	12.17	0.082	0.97	113.42	-1.60	30	-19.44	2:41 AM
5	4:00 AM	2.27	6.00	1.67	12.17	0.082	0.97	113.42	-1.60	30	-19.44	3:41 AM
6	5:00 AM	2.27	7.00	1.94	13.13	0.082	0.97	113.42	-1.60	30	-19.44	4:41 AM
7	6:00 AM	2.27	7.00	1.94	13.13	0.082	0.97	113.42	-1.60	30	-19.44	5:41 AM
8	7:00 AM	2.27	7.00	1.94	13.13	0.082	0.97	113.42	-1.60	30	-19.44	6:41 AM
9	8:00 AM	2.27	9.00	2.50	15.05	0.082	0.97	113.42	-1.60	30	-19.44	7:41 AM
10	9:00 AM	2.27	9.00	2.50	15.05	0.082	0.97	113.42	-1.60	30	-19.44	8:41 AM
11	10:00 AM	2.27	11.00	3.06	16.96	0.082	0.97	113.42	-1.60	30	-19.44	9:41 AM
12	11:00 AM	2.27	11.00	3.06	16.96	0.082	0.97	113.42	-1.60	30	-19.44	10:41 AM
13	12:00 PM	2.27	13.00	3.61	18.88	0.082	0.97	113.42	-1.60	30	-19.44	11:41 AM
14	1:00 PM	2.27	15.00	4.17	20.79	0.082	0.97	113.42	-1.60	30	-19.44	12:41 AM
15	2:00 PM	2.27	15.00	4.17	20.79	0.082	0.97	113.42	-1.60	30	-19.44	1:41 PM
16	3:00 PM	2.27	17.00	4.72	22.71	0.082	0.97	113.42	-1.60	30	-19.44	2:41 PM
17	4:00 PM	2.27	15.00	4.17	20.79	0.082	0.97	113.42	-1.60	30	-19.44	3:41 PM
18	5:00 PM	2.27	15.00	4.17	20.79	0.082	0.97	113.42	-1.60	30	-19.44	4:41 PM
19	6:00 PM	2.27	15.00	4.17	20.79	0.082	0.97	113.42	-1.60	30	-19.44	5:41 PM
20	7:00 PM	2.27	13.00	3.61	18.88	0.082	0.97	113.42	-1.60	30	-19.44	6:41 PM
21	8:00 PM	2.27	11.00	3.06	16.96	0.082	0.97	113.42	-1.60	30	-19.44	7:41 PM
22	9:00 PM	2.27	11.00	3.06	16.96	0.082	0.97	113.42	-1.60	30	-19.44	8:41 PM
23	10:00 PM	2.27	9.00	2.50	15.05	0.082	0.97	113.42	-1.60	30	-19.44	9:41 PM
24	11:00 PM	2.27	7.00	1.94	13.13	0.082	0.97	113.42	-1.60	30	-19.44	10:41 PM

Table B:5 Calculation Results Sheet No. 5 of Appendix B

Calculation for Experiment No.5 (16/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.14	4	1.11	10.26	0.082	0.97	114.41	1.49	30	-16.35	11:44 PM
2	1:00 AM	2.14	4	1.11	10.26	0.082	0.97	114.41	1.49	30	-16.35	12:44 AM
3	2:00 AM	2.14	7	1.94	13.13	0.082	0.97	114.41	1.49	30	-16.35	1:44 AM
4	3:00 AM	2.14	4	1.11	10.26	0.082	0.97	114.41	1.49	30	-16.35	2:44 AM
5	4:00 AM	2.14	6	1.67	12.17	0.082	0.97	114.41	1.49	30	-16.35	3:44 AM
6	5:00 AM	2.14	6	1.67	12.17	0.082	0.97	114.41	1.49	30	-16.35	4:44 AM
7	6:00 AM	2.14	6	1.67	12.17	0.082	0.97	114.41	1.49	30	-16.35	5:44 AM
8	7:00 AM	2.14	6	1.67	12.17	0.082	0.97	114.41	1.49	30	-16.35	6:44 AM
9	8:00 AM	2.14	6	1.67	12.17	0.082	0.97	114.41	1.49	30	-16.35	7:44 AM
10	9:00 AM	2.14	6	1.67	12.17	0.082	0.97	114.41	1.49	30	-16.35	8:44 AM
11	10:00 AM	2.14	9	2.50	15.05	0.082	0.97	114.41	1.49	30	-16.35	9:44 AM
12	11:00 AM	2.14	13	3.61	18.88	0.082	0.97	114.41	1.49	30	-16.35	10:44 AM
13	12:00 PM	2.14	13	3.61	18.88	0.082	0.97	114.41	1.49	30	-16.35	11:44 AM
14	1:00 PM	2.14	15	4.17	20.79	0.082	0.97	114.41	1.49	30	-16.35	12:44 AM
15	2:00 PM	2.14	17	4.72	22.71	0.082	0.97	114.41	1.49	30	-16.35	1:44 PM
16	3:00 PM	2.14	13	3.61	18.88	0.082	0.97	114.41	1.49	30	-16.35	2:44 PM
17	4:00 PM	2.14	17	4.72	22.71	0.082	0.97	114.41	1.49	30	-16.35	3:44 PM
18	5:00 PM	2.14	15	4.17	20.79	0.082	0.97	114.41	1.49	30	-16.35	4:44 PM
19	6:00 PM	2.14	13	3.61	18.88	0.082	0.97	114.41	1.49	30	-16.35	5:44 PM
20	7:00 PM	2.14	11	3.06	16.96	0.082	0.97	114.41	1.49	30	-16.35	6:44 PM
21	8:00 PM	2.14	11	3.06	16.96	0.082	0.97	114.41	1.49	30	-16.35	7:44 PM
22	9:00 PM	2.14	9	2.50	15.05	0.082	0.97	114.41	1.49	30	-16.35	8:44 PM
23	10:00 PM	2.14	7	1.94	13.13	0.082	0.97	114.41	1.49	30	-16.35	9:44 PM
24	11:00 PM	2.14	7	1.94	13.13	0.082	0.97	114.41	1.49	30	-16.35	10:44 PM

Table B:6 Calculation Results Sheet No. 6 of Appendix B

Calculation for Experiment No.6 (17/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.04	6.00	1.67	12.17	0.082	0.97	115.40	-5.91	30	-23.75	11:37 PM
2	1:00 AM	2.04	4.00	1.11	10.26	0.082	0.97	115.40	-5.91	30	-23.75	12:37 AM
3	2:00 AM	2.04	7.00	1.94	13.13	0.082	0.97	115.40	-5.91	30	-23.75	1:37 AM
4	3:00 AM	2.04	4.00	1.11	10.26	0.082	0.97	115.40	-5.91	30	-23.75	2:37AM
5	4:00 AM	2.04	4.00	1.11	10.26	0.082	0.97	115.40	-5.91	30	-23.75	3:37AM
6	5:00 AM	2.04	7.00	1.94	13.13	0.082	0.97	115.40	-5.91	30	-23.75	4:37 AM
7	6:00 AM	2.04	7.00	1.94	13.13	0.082	0.97	115.40	-5.91	30	-23.75	5:37 AM
8	7:00 AM	2.04	7.00	1.94	13.13	0.082	0.97	115.40	-5.91	30	-23.75	6:37 AM
9	8:00 AM	2.04	7.00	1.94	13.13	0.082	0.97	115.40	-5.91	30	-23.75	7:37 AM
10	9:00 AM	2.04	7.00	1.94	13.13	0.082	0.97	115.40	-5.91	30	-23.75	8:37 AM
11	10:00 AM	2.04	13.00	3.61	18.88	0.082	0.97	115.40	-5.91	30	-23.75	9:37AM
12	11:00 AM	2.04	13.00	3.61	18.88	0.082	0.97	115.40	-5.91	30	-23.75	10:37AM
13	12:00 PM	2.04	11.00	3.06	16.96	0.082	0.97	115.40	-5.91	30	-23.75	11:37 AM
14	1:00 PM	2.04	17.00	4.72	22.71	0.082	0.97	115.40	-5.91	30	-23.75	12:37AM
15	2:00 PM	2.04	17.00	4.72	22.71	0.082	0.97	115.40	-5.91	30	-23.75	1:37PM
16	3:00 PM	2.04	13.00	3.61	18.88	0.082	0.97	115.40	-5.91	30	-23.75	2:37 PM
17	4:00 PM	2.04	17.00	4.72	22.71	0.082	0.97	115.40	-5.91	30	-23.75	3:37PM
18	5:00 PM	2.04	17.00	4.72	22.71	0.082	0.97	115.40	-5.91	30	-23.75	4:37PM
19	6:00 PM	2.04	13.00	3.61	18.88	0.082	0.97	115.40	-5.91	30	-23.75	5:37 PM
20	7:00 PM	2.04	13.00	3.61	18.88	0.082	0.97	115.40	-5.91	30	-23.75	6:37PM
21	8:00 PM	2.04	11.00	3.06	16.96	0.082	0.97	115.40	-5.91	30	-23.75	7:37PM
22	9:00 PM	2.04	9.00	2.50	15.05	0.082	0.97	115.40	-5.91	30	-23.75	8:37PM
23	10:00 PM	2.04	7.00	1.94	13.13	0.082	0.97	115.40	-5.91	30	-23.75	9:37PM
24	11:00 PM	2.04	6.00	1.67	12.17	0.082	0.97	115.40	-5.91	30	-23.75	10:37PM

Table B:7 Calculation Results Sheet No. 7 of Appendix B

Calculation for Experiment No.7 (18/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.23	6.00	1.67	12.17	0.082	0.97	116.38	10.48	30	-7.36	11:53 PM
2	1:00 AM	2.23	4.00	1.11	10.26	0.082	0.97	116.38	10.48	30	-7.36	12:53 AM
3	2:00 AM	2.23	4.00	1.11	10.26	0.082	0.97	116.38	10.48	30	-7.36	1:53 AM
4	3:00 AM	2.23	6.00	1.67	12.17	0.082	0.97	116.38	10.48	30	-7.36	2:53AM
5	4:00 AM	2.23	4.00	1.11	10.26	0.082	0.97	116.38	10.48	30	-7.36	3:53AM
6	5:00 AM	2.23	6.00	1.67	12.17	0.082	0.97	116.38	10.48	30	-7.36	4:53 AM
7	6:00 AM	2.23	6.00	1.67	12.17	0.082	0.97	116.38	10.48	30	-7.36	5:53 AM
8	7:00 AM	2.23	7.00	1.94	13.13	0.082	0.97	116.38	10.48	30	-7.36	6:53 AM
9	8:00 AM	2.23	11.00	3.06	16.96	0.082	0.97	116.38	10.48	30	-7.36	7:53 AM
10	9:00 AM	2.23	11.00	3.06	16.96	0.082	0.97	116.38	10.48	30	-7.36	8:53AM
11	10:00 AM	2.23	13.00	3.61	18.88	0.082	0.97	116.38	10.48	30	-7.36	9:53AM
12	11:00 AM	2.23	15.00	4.17	20.79	0.082	0.97	116.38	10.48	30	-7.36	10:53AM
13	12:00 PM	2.23	13.00	3.61	18.88	0.082	0.97	116.38	10.48	30	-7.36	11:53 AM
14	1:00 PM	2.23	15.00	4.17	20.79	0.082	0.97	116.38	10.48	30	-7.36	12:53AM
15	2:00 PM	2.23	17.00	4.72	22.71	0.082	0.97	116.38	10.48	30	-7.36	1:53PM
16	3:00 PM	2.23	13.00	3.61	18.88	0.082	0.97	116.38	10.48	30	-7.36	2:53PM
17	4:00 PM	2.23	17.00	4.72	22.71	0.082	0.97	116.38	10.48	30	-7.36	3:53PM
18	5:00 PM	2.23	17.00	4.72	22.71	0.082	0.97	116.38	10.48	30	-7.36	4:53PM
19	6:00 PM	2.23	15.00	4.17	20.79	0.082	0.97	116.38	10.48	30	-7.36	5:53PM
20	7:00 PM	2.23	13.00	3.61	18.88	0.082	0.97	116.38	10.48	30	-7.36	6:53PM
21	8:00 PM	2.23	11.00	3.06	16.96	0.082	0.97	116.38	10.48	30	-7.36	7:53PM
22	9:00 PM	2.23	7.00	1.94	13.13	0.082	0.97	116.38	10.48	30	-7.36	8:53PM
23	10:00 PM	2.23	7.00	1.94	13.13	0.082	0.97	116.38	10.48	30	-7.36	9:53PM
24	11:00 PM	2.23	6.00	1.67	12.17	0.082	0.97	116.38	10.48	30	-7.36	10:53PM

Table B:8 Calculation Results Sheet No. 8 of Appendix B

Calculation for Experiment No.8(19/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.13	9.00	2.50	15.05	0.082	0.97	117.37	12.17	30	-5.67	11:55 PM
2	1:00 AM	2.13	9.00	2.50	15.05	0.082	0.97	117.37	12.17	30	-5.67	12:55 AM
3	2:00 AM	2.13	9.00	2.50	15.05	0.082	0.97	117.37	12.17	30	-5.67	1:55 AM
4	3:00 AM	2.13	6.00	1.67	12.17	0.082	0.97	117.37	12.17	30	-5.67	2:55AM
5	4:00 AM	2.13	6.00	1.67	12.17	0.082	0.97	117.37	12.17	30	-5.67	3:55AM
6	5:00 AM	2.13	6.00	1.67	12.17	0.082	0.97	117.37	12.17	30	-5.67	4:55 AM
7	6:00 AM	2.13	6.00	1.67	12.17	0.082	0.97	117.37	12.17	30	-5.67	5:55 AM
8	7:00 AM	2.13	7.00	1.94	13.13	0.082	0.97	117.37	12.17	30	-5.67	6:55 AM
9	8:00 AM	2.13	7.00	1.94	13.13	0.082	0.97	117.37	12.17	30	-5.67	7:55 AM
10	9:00 AM	2.13	7.00	1.94	13.13	0.082	0.97	117.37	12.17	30	-5.67	8:55AM
11	10:00 AM	2.13	9.00	2.50	15.05	0.082	0.97	117.37	12.17	30	-5.67	9:55AM
12	11:00 AM	2.13	13.00	3.61	18.88	0.082	0.97	117.37	12.17	30	-5.67	10:55AM
13	12:00 PM	2.13	11.00	3.06	16.96	0.082	0.97	117.37	12.17	30	-5.67	11:55 AM
14	1:00 PM	2.13	15.00	4.17	20.79	0.082	0.97	117.37	12.17	30	-5.67	12:55AM
15	2:00 PM	2.13	18.00	5.00	23.66	0.082	0.97	117.37	12.17	30	-5.67	1:55PM
16	3:00 PM	2.13	15.00	4.17	20.79	0.082	0.97	117.37	12.17	30	-5.67	2:55PM
17	4:00 PM	2.13	17.00	4.72	22.71	0.082	0.97	117.37	12.17	30	-5.67	3:55PM
18	5:00 PM	2.13	17.00	4.72	22.71	0.082	0.97	117.37	12.17	30	-5.67	4:55PM
19	6:00 PM	2.13	13.00	3.61	18.88	0.082	0.97	117.37	12.17	30	-5.67	5:55PM
20	7:00 PM	2.13	11.00	3.06	16.96	0.082	0.97	117.37	12.17	30	-5.67	6:55PM
21	8:00 PM	2.13	9.00	2.50	15.05	0.082	0.97	117.37	12.17	30	-5.67	7:55PM
22	9:00 PM	2.13	7.00	1.94	13.13	0.082	0.97	117.37	12.17	30	-5.67	8:55PM
23	10:00 PM	2.13	6.00	1.67	12.17	0.082	0.97	117.37	12.17	30	-5.67	9:55PM
24	11:00 PM	2.13	4.00	1.11	10.26	0.082	0.97	117.37	12.17	30	-5.67	10:55PM

Table B:9 Calculation Results Sheet No. 9 of Appendix B

Calculation for Experiment No.9(20/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.09	6.00	1.67	12.17	0.082	0.97	118.36	-11.40	30	-29.24	11:31 PM
2	1:00 AM	2.09	4.00	1.11	10.26	0.082	0.97	118.36	-11.40	30	-29.24	12:31AM
3	2:00 AM	2.09	4.00	1.11	10.26	0.082	0.97	118.36	-11.40	30	-29.24	1:31 AM
4	3:00 AM	2.09	7.00	1.94	13.13	0.082	0.97	118.36	-11.40	30	-29.24	2:31AM
5	4:00 AM	2.09	7.00	1.94	13.13	0.082	0.97	118.36	-11.40	30	-29.24	3:31AM
6	5:00 AM	2.09	11.00	3.06	16.96	0.082	0.97	118.36	-11.40	30	-29.24	4:31AM
7	6:00 AM	2.09	9.00	2.50	15.05	0.082	0.97	118.36	-11.40	30	-29.24	5:31AM
8	7:00 AM	2.09	9.00	2.50	15.05	0.082	0.97	118.36	-11.40	30	-29.24	6:31 AM
9	8:00 AM	2.09	7.00	1.94	13.13	0.082	0.97	118.36	-11.40	30	-29.24	7:31 AM
10	9:00 AM	2.09	7.00	1.94	13.13	0.082	0.97	118.36	-11.40	30	-29.24	8:31AM
11	10:00 AM	2.09	9.00	2.50	15.05	0.082	0.97	118.36	-11.40	30	-29.24	9:31AM
12	11:00 AM	2.09	11.00	3.06	16.96	0.082	0.97	118.36	-11.40	30	-29.24	10:31AM
13	12:00 PM	2.09	9.00	2.50	15.05	0.082	0.97	118.36	-11.40	30	-29.24	11:31 AM
14	1:00 PM	2.09	13.00	3.61	18.88	0.082	0.97	118.36	-11.40	30	-29.24	12:31AM
15	2:00 PM	2.09	15.00	4.17	20.79	0.082	0.97	118.36	-11.40	30	-29.24	1:31PM
16	3:00 PM	2.09	13.00	3.61	18.88	0.082	0.97	118.36	-11.40	30	-29.24	2:31PM
17	4:00 PM	2.09	15.00	4.17	20.79	0.082	0.97	118.36	-11.40	30	-29.24	3:31PM
18	5:00 PM	2.09	15.00	4.17	20.79	0.082	0.97	118.36	-11.40	30	-29.24	4:31PM
19	6:00 PM	2.09	13.00	3.61	18.88	0.082	0.97	118.36	-11.40	30	-29.24	5:31PM
20	7:00 PM	2.09	13.00	3.61	18.88	0.082	0.97	118.36	-11.40	30	-29.24	6:31PM
21	8:00 PM	2.09	11.00	3.06	16.96	0.082	0.97	118.36	-11.40	30	-29.24	7:31PM
22	9:00 PM	2.09	7.00	1.94	13.13	0.082	0.97	118.36	-11.40	30	-29.24	8:31PM
23	10:00 PM	2.09	6.00	1.67	12.17	0.082	0.97	118.36	-11.40	30	-29.24	9:31PM
24	11:00 PM	2.09	6.00	1.67	12.17	0.082	0.97	118.36	-11.40	30	-29.24	10:31PM

Table B:10 Calculation Results Sheet No. 10 of Appendix B

Calculation for Experiment No.10(21/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.00	6.00	1.67	12.17	0.082	0.97	119.34	-8.22	30	-26.06	11:34 PM
2	1:00 AM	2.00	4.00	1.11	10.26	0.082	0.97	119.34	-8.22	30	-26.06	12:34AM
3	2:00 AM	2.00	4.00	1.11	10.26	0.082	0.97	119.34	-8.22	30	-26.06	1:34AM
4	3:00 AM	2.00	4.00	1.11	10.26	0.082	0.97	119.34	-8.22	30	-26.06	2:34AM
5	4:00 AM	2.00	6.00	1.67	12.17	0.082	0.97	119.34	-8.22	30	-26.06	3:34AM
6	5:00 AM	2.00	6.00	1.67	12.17	0.082	0.97	119.34	-8.22	30	-26.06	4:34AM
7	6:00 AM	2.00	6.00	1.67	12.17	0.082	0.97	119.34	-8.22	30	-26.06	5:34AM
8	7:00 AM	2.00	6.00	1.67	12.17	0.082	0.97	119.34	-8.22	30	-26.06	6:34 AM
9	8:00 AM	2.00	6.00	1.67	12.17	0.082	0.97	119.34	-8.22	30	-26.06	7:34 AM
10	9:00 AM	2.00	7.00	1.94	13.13	0.082	0.97	119.34	-8.22	30	-26.06	8:34AM
11	10:00 AM	2.00	9.00	2.50	15.05	0.082	0.97	119.34	-8.22	30	-26.06	9:34AM
12	11:00 AM	2.00	9.00	2.50	15.05	0.082	0.97	119.34	-8.22	30	-26.06	10:34AM
13	12:00 PM	2.00	9.00	2.50	15.05	0.082	0.97	119.34	-8.22	30	-26.06	11:34 AM
14	1:00 PM	2.00	13.00	3.61	18.88	0.082	0.97	119.34	-8.22	30	-26.06	12:34AM
15	2:00 PM	2.00	13.00	3.61	18.88	0.082	0.97	119.34	-8.22	30	-26.06	1:34PM
16	3:00 PM	2.00	11.00	3.06	16.96	0.082	0.97	119.34	-8.22	30	-26.06	2:34PM
17	4:00 PM	2.00	15.00	4.17	20.79	0.082	0.97	119.34	-8.22	30	-26.06	3:34PM
18	5:00 PM	2.00	15.00	4.17	20.79	0.082	0.97	119.34	-8.22	30	-26.06	4:34PM
19	6:00 PM	2.00	17.00	4.72	22.71	0.082	0.97	119.34	-8.22	30	-26.06	5:34PM
20	7:00 PM	2.00	15.00	4.17	20.79	0.082	0.97	119.34	-8.22	30	-26.06	6:34PM
21	8:00 PM	2.00	13.00	3.61	18.88	0.082	0.97	119.34	-8.22	30	-26.06	7:34PM
22	9:00 PM	2.00	11.00	3.06	16.96	0.082	0.97	119.34	-8.22	30	-26.06	8:34PM
23	10:00 PM	2.00	9.00	2.50	15.05	0.082	0.97	119.34	-8.22	30	-26.06	9:34PM
24	11:00 PM	2.00	7.00	1.94	13.13	0.082	0.97	119.34	-8.22	30	-26.06	10:34PM

Table B:11 Calculation Results Sheet No. 11 of Appendix B

Calculation for Experiment No.11(22/7/2015)												
No of hours	Time (hours)	e	U <sub>2</sub> (Km/h)	U <sub>2</sub> (m/s)	F(u)	Gs	dr	D deg	ET	LSTM	AST* (MIN)	AST
1	12:00 AM	2.16	7.00	1.94	13.13	0.082	0.97	120.33	3.74	30	-14.10	11:46 PM
2	1:00 AM	2.16	4.00	1.11	10.26	0.082	0.97	120.33	3.74	30	-14.10	12:46AM
3	2:00 AM	2.16	4.00	1.11	10.26	0.082	0.97	120.33	3.74	30	-14.10	1:46AM
4	3:00 AM	2.16	6.00	1.67	12.17	0.082	0.97	120.33	3.74	30	-14.10	2:46AM
5	4:00 AM	2.16	2.00	0.56	8.34	0.082	0.97	120.33	3.74	30	-14.10	3:46AM
6	5:00 AM	2.16	4.00	1.11	10.26	0.082	0.97	120.33	3.74	30	-14.10	4:46AM
7	6:00 AM	2.16	6.00	1.67	12.17	0.082	0.97	120.33	3.74	30	-14.10	5:46AM
8	7:00 AM	2.16	6.00	1.67	12.17	0.082	0.97	120.33	3.74	30	-14.10	6:46 AM
9	8:00 AM	2.16	6.00	1.67	12.17	0.082	0.97	120.33	3.74	30	-14.10	7:46 AM
10	9:00 AM	2.16	6.00	1.67	12.17	0.082	0.97	120.33	3.74	30	-14.10	8:46AM
11	10:00 AM	2.16	9.00	2.50	15.05	0.082	0.97	120.33	3.74	30	-14.10	9:46AM
12	11:00 AM	2.16	7.00	1.94	13.13	0.082	0.97	120.33	3.74	30	-14.10	10:46AM
13	12:00 PM	2.16	7.00	1.94	13.13	0.082	0.97	120.33	3.74	30	-14.10	11:46 AM
14	1:00 PM	2.16	13.00	3.61	18.88	0.082	0.97	120.33	3.74	30	-14.10	12:46AM
15	2:00 PM	2.16	15.00	4.17	20.79	0.082	0.97	120.33	3.74	30	-14.10	1:46PM
16	3:00 PM	2.16	11.00	3.06	16.96	0.082	0.97	120.33	3.74	30	-14.10	2:46PM
17	4:00 PM	2.16	17.00	4.72	22.71	0.082	0.97	120.33	3.74	30	-14.10	3:46PM
18	5:00 PM	2.16	17.00	4.72	22.71	0.082	0.97	120.33	3.74	30	-14.10	4:46PM
19	6:00 PM	2.16	15.00	4.17	20.79	0.082	0.97	120.33	3.74	30	-14.10	5:46PM
20	7:00 PM	2.16	17.00	4.72	22.71	0.082	0.97	120.33	3.74	30	-14.10	6:46PM
21	8:00 PM	2.16	13.00	3.61	18.88	0.082	0.97	120.33	3.74	30	-14.10	7:46PM
22	9:00 PM	2.16	11.00	3.06	16.96	0.082	0.97	120.33	3.74	30	-14.10	8:46PM
23	10:00 PM	2.16	9.00	2.50	15.05	0.082	0.97	120.33	3.74	30	-14.10	9:46PM
24	11:00 PM	2.16	7.00	1.94	13.13	0.082	0.97	120.33	3.74	30	-14.10	10:46PM

## Appendix (C)

Table C:1 Calculation Results Sheet No. 1 of Appendix C

Calculation for Experiment No.1 (12/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	179.5	1.14	65.34	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
2	1:00 AM	-165.5	0.57	32.60	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
3	2:00 AM	-150.5	-1.23	-70.71	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
4	3:00 AM	-135.5	1.16	66.35	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
5	4:00 AM	-120.5	-0.44	-25.29	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
6	5:00 AM	-105.5	-0.25	-14.25	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
7	6:00 AM	-90.5	0.96	55.28	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
8	7:00 AM	-75.5	-1.38	-79.11	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
9	8:00 AM	-60.5	0.76	43.69	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
10	9:00 AM	-45.5	-0.05	-2.68	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
11	10:00 AM	-30.5	-0.64	-36.79	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
12	11:00 AM	-15.5	1.36	77.82	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
13	12:00 PM	-0.5	-1.05	-59.95	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
14	1:00 PM	14.5	0.37	21.00	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
15	2:00 PM	29.5	0.35	19.99	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
16	3:00 PM	44.5	-1.03	-58.99	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
17	4:00 PM	59.5	1.38	78.81	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
18	5:00 PM	74.5	-0.66	-37.79	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
19	6:00 PM	89.5	-0.03	-1.68	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
20	7:00 PM	104.5	0.74	42.68	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
21	8:00 PM	119.5	-1.37	-78.54	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
22	9:00 PM	134.5	0.98	56.29	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
23	10:00 PM	149.5	-0.27	-15.26	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22
24	11:00 PM	164.5	-0.42	-24.29	0.38	21.93	34.46	0.55	31.52	104.30	1.82	40.81	797.22

Table C:2 Calculation Results Sheet No. 2 of Appendix C

Calculation for Experiment No.2 (13/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	176.5	-0.93	-53.05	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
2	1:00 AM	-168.5	-0.39	-22.38	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
3	2:00 AM	-153.5	1.13	64.59	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
4	3:00 AM	-138.5	-1.16	-66.68	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
5	4:00 AM	-123.5	0.60	34.43	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
6	5:00 AM	-108.5	0.13	7.63	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
7	6:00 AM	-93.5	-0.77	-43.92	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
8	7:00 AM	-78.5	1.47	83.97	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
9	8:00 AM	-63.5	-0.84	-48.08	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
10	9:00 AM	-48.5	0.21	12.08	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
11	10:00 AM	-33.5	0.52	29.96	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
12	11:00 AM	-18.5	-1.11	-63.47	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
13	12:00 PM	-3.5	1.20	68.96	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
14	1:00 PM	11.5	-0.47	-26.75	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
15	2:00 PM	26.5	-0.18	-10.15	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
16	3:00 PM	41.5	0.91	52.28	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
17	4:00 PM	56.5	-1.26	-72.26	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
18	5:00 PM	71.5	0.82	46.84	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
19	6:00 PM	86.5	-0.08	-4.73	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
20	7:00 PM	101.5	-0.56	-32.06	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
21	8:00 PM	116.5	1.29	74.20	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
22	9:00 PM	131.5	-1.03	-59.08	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
23	10:00 PM	146.5	0.43	24.49	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41
24	11:00 PM	161.5	0.31	17.54	0.38	21.79	34.46	0.55	31.52	104.20	1.82	40.76	796.41

Table C:3 Calculation Results Sheet No. 3 of Appendix C

Calculation for Experiment No.3 (14/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	172	0.77	43.97	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
2	1:00 AM	-173	1.25	71.46	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
3	2:00 AM	-158	-0.56	-31.94	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
4	3:00 AM	-143	-0.02	-1.01	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
5	4:00 AM	-128	0.75	43.04	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
6	5:00 AM	-113	-1.10	-63.22	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
7	6:00 AM	-98	0.93	53.18	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
8	7:00 AM	-83	-0.20	-11.36	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
9	8:00 AM	-68	-0.38	-22.01	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
10	9:00 AM	-53	1.10	63.23	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
11	10:00 AM	-38	-1.03	-58.79	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
12	11:00 AM	-23	0.56	32.22	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
13	12:00 PM	-8	0.17	9.89	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
14	1:00 PM	7	-0.73	-41.88	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
15	2:00 PM	22	1.32	75.70	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
16	3:00 PM	37	-0.75	-42.71	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
17	4:00 PM	52	0.19	10.84	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
18	5:00 PM	67	0.55	31.27	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
19	6:00 PM	82	-1.02	-58.23	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
20	7:00 PM	97	1.12	64.06	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
21	8:00 PM	112	-0.40	-22.92	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
22	9:00 PM	127	-0.18	-10.42	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
23	10:00 PM	142	0.91	52.27	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56
24	11:00 PM	157	-1.11	-63.41	0.38	21.64	34.46	0.55	31.52	104.09	1.82	40.71	795.56

Table C:4 Calculation Results Sheet No. 4 of Appendix C

Calculation for Experiment No.4 (15/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	175.25	-0.67	-38.61	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
2	1:00 AM	-169.75	-0.95	-54.27	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
3	2:00 AM	-154.75	0.70	40.36	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
4	3:00 AM	-139.75	0.01	0.39	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
5	4:00 AM	-124.75	-0.50	-28.61	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
6	5:00 AM	-109.75	1.12	64.14	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
7	6:00 AM	-94.75	-0.79	-45.18	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
8	7:00 AM	-79.75	0.36	20.91	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
9	8:00 AM	-64.75	0.35	20.25	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
10	9:00 AM	-49.75	-0.78	-44.73	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
11	10:00 AM	-34.75	1.12	64.44	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
12	11:00 AM	-19.75	-0.51	-29.21	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
13	12:00 PM	-4.75	0.02	1.05	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
14	1:00 PM	10.25	0.69	39.73	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
15	2:00 PM	25.25	-0.94	-54.14	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
16	3:00 PM	40.25	0.88	50.46	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
17	4:00 PM	55.25	-0.18	-10.50	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
18	5:00 PM	70.25	-0.32	-18.38	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
19	6:00 PM	85.25	1.00	57.17	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
20	7:00 PM	100.25	-0.90	-51.48	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
21	8:00 PM	115.25	0.56	31.84	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
22	9:00 PM	130.25	0.16	9.20	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
23	10:00 PM	145.25	-0.63	-36.26	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67
24	11:00 PM	160.25	1.16	66.60	0.37	21.48	34.46	0.55	31.52	103.97	1.81	40.66	794.67

Table C:5 Calculation Results Sheet No. 5 of Appendix C

Calculation for Experiment No.5 (16/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	176	-0.79	-45.15	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
2	1:00 AM	-169	-0.59	-33.68	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
3	2:00 AM	-154	1.00	57.07	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
4	3:00 AM	-139	-0.51	-29.48	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
5	4:00 AM	-124	0.14	7.87	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
6	5:00 AM	-109	0.54	30.84	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
7	6:00 AM	-94	-0.76	-43.41	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
8	7:00 AM	-79	0.86	49.48	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
9	8:00 AM	-64	-0.24	-13.83	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
10	9:00 AM	-49	-0.17	-9.68	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
11	10:00 AM	-34	0.81	46.33	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
12	11:00 AM	-19	-0.78	-44.60	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
13	12:00 PM	-4	0.61	34.90	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
14	1:00 PM	11	0.06	3.53	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
15	2:00 PM	26	-0.45	-25.91	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
16	3:00 PM	41	0.98	56.21	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
17	4:00 PM	56	-0.64	-36.65	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
18	5:00 PM	71	0.31	17.74	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
19	6:00 PM	86	0.37	21.27	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
20	7:00 PM	101	-0.68	-38.83	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
21	8:00 PM	116	0.96	54.97	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
22	9:00 PM	131	-0.40	-22.85	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
23	10:00 PM	146	0.00	-0.01	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76
24	11:00 PM	161	0.67	38.12	0.37	21.32	34.46	0.55	31.52	103.85	1.81	40.61	793.76

Table C:6 Calculation Results Sheet No. 6 of Appendix C

Calculation for Experiment No.6 (17/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	174.25	0.15	8.58	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
2	1:00 AM	-170.75	-0.22	-12.63	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
3	2:00 AM	-155.75	-0.08	-4.56	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
4	3:00 AM	-140.75	0.66	37.84	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
5	4:00 AM	-125.75	-0.62	-35.35	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
6	5:00 AM	-110.75	0.57	32.65	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
7	6:00 AM	-95.75	0.03	1.87	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
8	7:00 AM	-80.75	-0.32	-18.38	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
9	8:00 AM	-65.75	0.80	46.08	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
10	9:00 AM	-50.75	-0.53	-30.34	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
11	10:00 AM	-35.75	0.33	18.73	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
12	11:00 AM	-20.75	0.30	16.92	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
13	12:00 PM	-5.75	-0.51	-29.31	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
14	1:00 PM	9.25	0.81	46.60	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
15	2:00 PM	24.25	-0.35	-19.91	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
16	3:00 PM	39.25	0.06	3.71	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
17	4:00 PM	54.25	0.54	31.07	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
18	5:00 PM	69.25	-0.61	-35.10	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
19	6:00 PM	84.25	0.68	39.16	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
20	7:00 PM	99.25	-0.11	-6.34	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
21	8:00 PM	114.25	-0.19	-10.93	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
22	9:00 PM	129.25	0.74	42.27	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
23	10:00 PM	144.25	-0.59	-33.94	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81
24	11:00 PM	159.25	0.47	26.72	0.37	21.14	34.46	0.55	31.52	103.73	1.81	40.55	792.81

Table C:7 Calculation Results Sheet No. 7 of Appendix C

Calculation for Experiment No.7 (18/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	178.25	0.46	26.19	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
2	1:00 AM	-166.75	0.63	36.19	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
3	2:00 AM	-151.75	-0.21	-12.16	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
4	3:00 AM	-136.75	0.04	2.40	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
5	4:00 AM	-121.75	0.48	27.35	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
6	5:00 AM	-106.75	-0.44	-25.31	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
7	6:00 AM	-91.75	0.53	30.17	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
8	7:00 AM	-76.75	-0.02	-1.36	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
9	8:00 AM	-61.75	-0.15	-8.87	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
10	9:00 AM	-46.75	0.61	34.77	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
11	10:00 AM	-31.75	-0.41	-23.58	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
12	11:00 AM	-16.75	0.36	20.47	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
13	12:00 PM	-1.75	0.18	10.42	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
14	1:00 PM	13.25	-0.32	-18.20	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
15	2:00 PM	28.25	0.65	37.29	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
16	3:00 PM	43.25	-0.30	-17.22	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
17	4:00 PM	58.25	0.16	8.98	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
18	5:00 PM	73.25	0.38	21.79	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
19	6:00 PM	88.25	-0.42	-24.06	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
20	7:00 PM	103.25	0.60	34.09	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
21	8:00 PM	118.25	-0.13	-7.57	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
22	9:00 PM	133.25	-0.05	-2.76	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
23	10:00 PM	148.25	0.54	31.14	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83
24	11:00 PM	163.25	-0.44	-25.17	0.37	20.97	34.46	0.55	31.52	103.60	1.81	40.49	791.83

Table C:8 Calculation Results Sheet No. 8 of Appendix C

Calculation for Experiment No.8 (19/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	178.75	0.45	25.65	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
2	1:00 AM	-166.25	0.46	26.08	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
3	2:00 AM	-151.25	-0.22	-12.77	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
4	3:00 AM	-136.25	0.24	13.76	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
5	4:00 AM	-121.25	0.20	11.61	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
6	5:00 AM	-106.25	-0.20	-11.65	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
7	6:00 AM	-91.25	0.46	26.57	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
8	7:00 AM	-76.25	-0.14	-7.82	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
9	8:00 AM	-61.25	0.10	5.80	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
10	9:00 AM	-46.25	0.33	18.92	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
11	10:00 AM	-31.25	-0.25	-14.59	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
12	11:00 AM	-16.25	0.41	23.59	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
13	12:00 PM	-1.25	-0.01	-0.83	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
14	1:00 PM	13.75	-0.04	-2.09	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
15	2:00 PM	28.75	0.42	24.31	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
16	3:00 PM	43.75	-0.25	-14.32	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
17	4:00 PM	58.75	0.31	17.80	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
18	5:00 PM	73.75	0.12	7.15	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
19	6:00 PM	88.75	-0.15	-8.81	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
20	7:00 PM	103.75	0.47	26.74	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
21	8:00 PM	118.75	-0.19	-10.88	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
22	9:00 PM	133.75	0.18	10.29	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
23	10:00 PM	148.75	0.26	15.02	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82
24	11:00 PM	163.75	-0.23	-13.33	0.36	20.78	34.46	0.55	31.52	103.47	1.81	40.43	790.82

Table C:9 Calculation Results Sheet No. 9 of Appendix C

Calculation for Experiment No.9(20/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	172.75	0.28	15.95	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
2	1:00 AM	-172.25	0.25	14.51	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
3	2:00 AM	-157.25	-0.07	-3.88	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
4	3:00 AM	-142.25	0.21	12.27	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
5	4:00 AM	-127.25	0.11	6.03	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
6	5:00 AM	-112.25	-0.01	-0.68	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
7	6:00 AM	-97.25	0.28	15.86	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
8	7:00 AM	-82.25	-0.04	-2.47	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
9	8:00 AM	-67.25	0.15	8.76	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
10	9:00 AM	-52.25	0.17	9.89	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
11	10:00 AM	-37.25	-0.05	-3.05	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
12	11:00 AM	-22.25	0.27	15.61	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
13	12:00 PM	-7.25	0.00	0.25	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
14	1:00 PM	7.75	0.08	4.84	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
15	2:00 PM	22.75	0.23	13.15	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
16	3:00 PM	37.75	-0.07	-4.02	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
17	4:00 PM	52.75	0.24	13.82	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
18	5:00 PM	67.75	0.07	3.85	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
19	6:00 PM	82.75	0.02	1.10	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
20	7:00 PM	97.75	0.27	15.29	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
21	8:00 PM	112.75	-0.06	-3.44	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
22	9:00 PM	127.75	0.19	10.80	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
23	10:00 PM	142.75	0.14	7.78	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78
24	11:00 PM	157.75	-0.03	-1.89	0.36	20.59	34.46	0.55	31.52	103.33	1.80	40.36	789.78

Table C:10 Calculation Results Sheet No. 10 of Appendix C

Calculation for Experiment No.10(21/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	173.50	0.09	5.05	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
2	1:00 AM	-171.50	0.10	5.62	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
3	2:00 AM	-156.50	0.12	6.97	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
4	3:00 AM	-141.50	0.08	4.76	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
5	4:00 AM	-126.50	0.12	6.77	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
6	5:00 AM	-111.50	0.10	5.93	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
7	6:00 AM	-96.50	0.09	5.20	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
8	7:00 AM	-81.50	0.12	7.15	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
9	8:00 AM	-66.50	0.09	4.92	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
10	9:00 AM	-51.50	0.11	6.36	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
11	10:00 AM	-36.50	0.11	6.40	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
12	11:00 AM	-21.50	0.09	4.90	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
13	12:00 PM	-6.50	0.12	7.14	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
14	1:00 PM	8.50	0.09	5.24	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
15	2:00 PM	23.50	0.10	5.89	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
16	3:00 PM	38.50	0.12	6.80	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
17	4:00 PM	53.50	0.08	4.76	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
18	5:00 PM	68.50	0.12	6.95	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
19	6:00 PM	83.50	0.10	5.67	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
20	7:00 PM	98.50	0.09	5.43	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
21	8:00 PM	113.50	0.12	7.08	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
22	9:00 PM	128.50	0.08	4.81	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
23	10:00 PM	143.50	0.12	6.60	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70
24	11:00 PM	158.50	0.11	6.14	0.36	20.40	34.46	0.55	31.52	103.19	1.80	40.30	788.70

Table C:11 Calculation Results Sheet No. 11 of Appendix C

Calculation for Experiment No.11(22/7/2015)													
No of hours	Time (hours)	$\omega$ , Deg	$\alpha$ , Rad.	$\alpha$ , Deg.	$\delta$ , Rad.	$\delta$ , Deg.	Long. Deg.	$\varphi$ , Rad.	$\varphi$ , Deg.	$\omega_s$ , Deg.	$\omega_s$ , Rad.	Ra	N
1	12:00 AM	176.5	0.29	16.62	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
2	1:00 AM	-168.5	0.19	11.06	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
3	2:00 AM	-153.5	-0.10	-5.60	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
4	3:00 AM	-138.5	0.32	18.24	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
5	4:00 AM	-123.5	-0.02	-1.22	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
6	5:00 AM	-108.5	0.08	4.37	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
7	6:00 AM	-93.5	0.27	15.21	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
8	7:00 AM	-78.5	-0.12	-6.78	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
9	8:00 AM	-63.5	0.28	15.88	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
10	9:00 AM	-48.5	0.06	3.37	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
11	10:00 AM	-33.5	-0.01	-0.37	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
12	11:00 AM	-18.5	0.31	17.92	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
13	12:00 PM	-3.5	-0.10	-5.99	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
14	1:00 PM	11.5	0.21	11.97	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
15	2:00 PM	26.5	0.15	8.38	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
16	3:00 PM	41.5	-0.07	-4.14	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
17	4:00 PM	56.5	0.33	18.70	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
18	5:00 PM	71.5	-0.06	-3.34	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
19	6:00 PM	86.5	0.12	7.16	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
20	7:00 PM	101.5	0.23	13.04	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
21	8:00 PM	116.5	-0.11	-6.36	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
22	9:00 PM	131.5	0.30	17.42	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
23	10:00 PM	146.5	0.01	0.72	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60
24	11:00 PM	161.5	0.04	2.18	0.35	20.20	34.46	0.55	31.52	103.04	1.80	40.23	787.60

## Appendix (D)

Table D:1 Calculation Results Sheet No. 1 of Appendix D

Calculation for Experiment No.1 (12/7/2015)														
Time (hours)	No of hours	Sunset time	Sunrise time	Actual duration of time	Constant $a_s$	Constant $b_s$	Rs	Constant a	Rns	$T_{max}, K$	$T_{min}, K$	$\sigma$	Rnl	Rn
1	12:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
2	1:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
3	2:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
4	3:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
5	4:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
6	5:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
7	6:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
8	7:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
9	8:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
10	9:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
11	10:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
12	11:00 AM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
13	12:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
14	1:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
15	2:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
16	3:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
17	4:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
18	5:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
19	6:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
20	7:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
21	8:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
22	9:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
23	10:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75
24	11:00 PM	5.46	19.49	14.30	0.25	0.50	10.57	0.30	7.40	305.16	295.16	4.903E-09	0.65	6.75

Table D:2 Calculation Results Sheet No. 2 of Appendix D

Calculation for Experiment No.2 (13/7/2015)														
Time (hours)	No of hours	Sunset time	Sunrise time	Actual duration of time	Constant a <sub>s</sub>	Constant b <sub>s</sub>	Rs	Constant a	Rns	Tmax,K	Tmin,K	σ	RnL	Rn
1	12:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
2	1:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
3	2:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
4	3:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
5	4:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
6	5:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
7	6:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
8	7:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
9	8:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
10	9:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
11	10:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
12	11:00 AM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
13	12:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
14	1:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
15	2:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
16	3:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
17	4:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
18	5:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
19	6:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
20	7:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
21	8:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
22	9:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
23	10:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73
24	11:00 PM	5.46	19.49	14.3	0.25	0.50	10.56	0.30	7.39	306.16	295.16	4.903E-09	0.66	6.73

Table D:3 Calculation Results Sheet No. 3 of Appendix D

Calculation for Experiment No.3(14/7/2015)														
Time (hours)	No of hours	Sunset time	Sunrise time	Actual duration of time	Constant $a_s$	Constant $b_s$	Rs	Constant a	Rns	Tmax,K	Tmin,K	$\sigma$	Rn1	Rn
1	12:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
2	1:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
3	2:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
4	3:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
5	4:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
6	5:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
7	6:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
8	7:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
9	8:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
10	9:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
11	10:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
12	11:00 AM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
13	12:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
14	1:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
15	2:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
16	3:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
17	4:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
18	5:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
19	6:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
20	7:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
21	8:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
22	9:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
23	10:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76
24	11:00 PM	5.47	19.49	14.2	0.25	0.50	10.54	0.30	7.38	307.16	296.16	4.903E-09	0.62	6.76

Table D:4 Calculation Results Sheet No. 4 of Appendix D

Calculation for Experiment No.4 (15/7/2015)														
Time (hours)	No of hours	Sunset time	Sunrise time	Actual duration of time	Constant $a_s$	Constant $b_s$	Rs	Constant a	Rns	Tmax,K	Tmin,K	$\sigma$	Rn1	Rn
1	12:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
2	1:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
3	2:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
4	3:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
5	4:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
6	5:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
7	6:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
8	7:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
9	8:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
10	9:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
11	10:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
12	11:00 AM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
13	12:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
14	1:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
15	2:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
16	3:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
17	4:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
18	5:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
19	6:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
20	7:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
21	8:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
22	9:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
23	10:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77
24	11:00 PM	5.48	19.48	14	0.25	0.50	10.52	0.30	7.37	303.16	297.16	4.903E-09	0.59	6.77

Table D:5 Calculation Results Sheet No. 5 of Appendix D

Calculation for Experiment No.5 (16/7/2015)														
Time (hours)	No of hours	Sunset time	Sunrise time	Actual duration of time	Constant $a_s$	Constant $b_s$	Rs	Constant a	Rns	$T_{max,K}$	$T_{min,K}$	$\sigma$	RnI	Rn
1	12:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
2	1:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
3	2:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
4	3:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
5	4:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
6	5:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
7	6:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
8	7:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
9	8:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
10	9:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
11	10:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
12	11:00 AM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
13	12:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
14	1:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
15	2:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
16	3:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
17	4:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
18	5:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
19	6:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
20	7:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
21	8:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
22	9:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
23	10:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73
24	11:00 PM	5.48	19.48	14	0.25	0.50	10.51	0.30	7.36	307.16	294.16	4.903E-09	0.63	6.73

Table D:6 Calculation Results Sheet No. 6 of Appendix D

Calculation for Experiment No.6 (17/7/2015)															
Time (hours)	No of hours	Sunset time	Sunrise time	Actual duration of time	Constant $a_s$	Constant $b_s$	Rs	Constant a	Rns	Tmax,K	Tmin,K	$\sigma$	Rnl	Rn	E (mm/d)
1	12:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.21
2	1:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.51
3	2:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.07
4	3:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.51
5	4:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.51
6	5:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.07
7	6:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.07
8	7:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.07
9	8:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.07
10	9:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.07
11	10:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.18
12	11:00 AM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.18
13	12:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.48
14	1:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	1.59
15	2:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	1.59
16	3:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.18
17	4:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	1.59
18	5:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	1.59
19	6:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.18
20	7:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.18
21	8:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.48
22	9:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	2.77
23	10:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.07
24	11:00 PM	5.49	19.48	13.59	0.25	0.50	10.48	0.30	7.34	307.16	295.16	4.903E-09	0.65	6.69	3.21

Table D:7 Calculation Results Sheet No. 7 of Appendix D

Calculation for Experiment No.7(18/7/2015)														
Time (hours)	No of hours	Sunset time	Sunrise time	Actual duration of time	Constant $a_s$	Constant $b_s$	Rs	Constant a	Rns	Tmax,K	Tmin,K	$\sigma$	Rnl	Rn
1	12:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
2	1:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
3	2:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
4	3:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
5	4:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
6	5:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
7	6:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
8	7:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
9	8:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
10	9:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
11	10:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
12	11:00 AM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
13	12:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
14	1:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
15	2:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
16	3:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
17	4:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
18	5:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
19	6:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
20	7:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
21	8:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
22	9:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
23	10:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72
24	11:00 PM	5.49	19.47	13.58	0.25	0.50	10.47	0.30	7.33	305.16	297.16	4.903E-09	0.61	6.72





## Appendix (E)

Table E:1 Calculation Results Sheet No. 1 of Appendix E

Calculation for Experiment No.1 (12/7/2015)											
Time (hours)	No of hours	B1	Length of pond side(m)	C1	x1y1	g, Mirror length(m)	SM1	B1(Rn)	G1	Abs U1	F1
1	12:00 AM	38	1	13.34	0.97	1	0.97	6.75	6.56	6.56	79.34
2	1:00 AM	38	1	-19.40	0.94	1	0.94	6.75	6.36	6.36	46.60
3	2:00 AM	38	1	-122.71	-0.54	1	-0.54	6.75	-3.64	3.64	-56.71
4	3:00 AM	38	1	14.35	0.97	1	0.97	6.75	6.53	6.53	80.35
5	4:00 AM	38	1	-77.29	0.22	1	0.22	6.75	1.48	1.48	-11.29
6	5:00 AM	38	1	-66.25	0.40	1	0.40	6.75	2.72	2.72	-0.25
7	6:00 AM	38	1	3.28	1.00	1	1.00	6.75	6.73	6.73	69.28
8	7:00 AM	38	1	-131.11	-0.66	1	-0.66	6.75	-4.43	4.43	-65.11
9	8:00 AM	38	1	-8.31	0.99	1	0.99	6.75	6.67	6.67	57.69
10	9:00 AM	38	1	-54.68	0.58	1	0.58	6.75	3.90	3.90	11.32
11	10:00 AM	38	1	-88.79	0.02	1	0.02	6.75	0.14	0.14	-22.79
12	11:00 AM	38	1	25.82	0.90	1	0.90	6.75	6.07	6.07	91.82
13	12:00 PM	38	1	-111.95	-0.37	1	-0.37	6.75	-2.52	2.52	-45.95
14	1:00 PM	38	1	-31.00	0.86	1	0.86	6.75	5.78	5.78	35.00
15	2:00 PM	38	1	-32.01	0.85	1	0.85	6.75	5.72	5.72	33.99
16	3:00 PM	38	1	-110.99	-0.36	1	-0.36	6.75	-2.41	2.41	-44.99
17	4:00 PM	38	1	26.81	0.89	1	0.89	6.75	6.02	6.02	92.81
18	5:00 PM	38	1	-89.79	0.00	1	0.00	6.75	0.03	0.03	-23.79
19	6:00 PM	38	1	-53.68	0.59	1	0.59	6.75	4.00	4.00	12.32
20	7:00 PM	38	1	-9.32	0.99	1	0.99	6.75	6.66	6.66	56.68
21	8:00 PM	38	1	-130.54	-0.65	1	-0.65	6.75	-4.38	4.38	-64.54
22	9:00 PM	38	1	4.29	1.00	1	1.00	6.75	6.73	6.73	70.29
23	10:00 PM	38	1	-67.26	0.39	1	0.39	6.75	2.61	2.61	-1.26
24	11:00 PM	38	1	-76.29	0.24	1	0.24	6.75	1.60	1.60	-10.29

Table E:2 Calculation Results Sheet No. 2 of Appendix E

Calculation for Experiment No.2 (13/7/2015)											
Time (hours)	No of hours	B1	Length of pond side(m)	C1	x1y1	g, Mirror length(m)	SM1	B1(Rn)	G1	Abs U1	F1
1	12:00 AM	35	1	-108.05	-0.31	1	-0.31	6.73	-2.09	2.09	-33.05
2	1:00 AM	35	1	-77.38	0.22	1	0.22	6.73	1.47	1.47	-2.38
3	2:00 AM	35	1	9.59	0.99	1	0.99	6.73	6.64	6.64	84.59
4	3:00 AM	35	1	-121.68	-0.53	1	-0.53	6.73	-3.54	3.54	-46.68
5	4:00 AM	35	1	-20.57	0.94	1	0.94	6.73	6.30	6.30	54.43
6	5:00 AM	35	1	-47.37	0.68	1	0.68	6.73	4.56	4.56	27.63
7	6:00 AM	35	1	-98.92	-0.15	1	-0.15	6.73	-1.04	1.04	-23.92
8	7:00 AM	35	1	28.97	0.87	1	0.87	6.73	5.89	5.89	103.97
9	8:00 AM	35	1	-103.08	-0.23	1	-0.23	6.73	-1.52	1.52	-28.08
10	9:00 AM	35	1	-42.92	0.73	1	0.73	6.73	4.93	4.93	32.08
11	10:00 AM	35	1	-25.04	0.91	1	0.91	6.73	6.10	6.10	49.96
12	11:00 AM	35	1	-118.47	-0.48	1	-0.48	6.73	-3.21	3.21	-43.47
13	12:00 PM	35	1	13.96	0.97	1	0.97	6.73	6.53	6.53	88.96
14	1:00 PM	35	1	-81.75	0.14	1	0.14	6.73	0.97	0.97	-6.75
15	2:00 PM	35	1	-65.15	0.42	1	0.42	6.73	2.83	2.83	9.85
16	3:00 PM	35	1	-2.72	1.00	1	1.00	6.73	6.73	6.73	72.28
17	4:00 PM	35	1	-127.26	-0.61	1	-0.61	6.73	-4.08	4.08	-52.26
18	5:00 PM	35	1	-8.16	0.99	1	0.99	6.73	6.67	6.67	66.84
19	6:00 PM	35	1	-59.73	0.50	1	0.50	6.73	3.39	3.39	15.27
20	7:00 PM	35	1	-87.06	0.05	1	0.05	6.73	0.35	0.35	-12.06
21	8:00 PM	35	1	19.20	0.94	1	0.94	6.73	6.36	6.36	94.20
22	9:00 PM	35	1	-114.08	-0.41	1	-0.41	6.73	-2.75	2.75	-39.08
23	10:00 PM	35	1	-30.51	0.86	1	0.86	6.73	5.80	5.80	44.49
24	11:00 PM	35	1	-37.46	0.79	1	0.79	6.73	5.34	5.34	37.54

Table E:3 Calculation Results Sheet No. 3 of Appendix E

Calculation for Experiment No.3 (14/7/2015)											
Time (hours)	No of hours	$\beta_1$	Length of pond side(m)	C1	x1y1	g, Mirror length(m)	SM1	B1(Rn)	G1	Abs U1	F1
1	12:00 AM	45	1	-1.03	1.00	1	1.00	6.76	6.76	6.76	43.97
2	1:00 AM	45	1	26.46	0.90	1	0.90	6.76	6.05	6.05	71.46
3	2:00 AM	45	1	-76.94	0.23	1	0.23	6.76	1.53	1.53	-31.94
4	3:00 AM	45	1	-46.01	0.69	1	0.69	6.76	4.69	4.69	-1.01
5	4:00 AM	45	1	-1.96	1.00	1	1.00	6.76	6.76	6.76	43.04
6	5:00 AM	45	1	-108.22	-0.31	1	-0.31	6.76	-2.11	2.11	-63.22
7	6:00 AM	45	1	8.18	0.99	1	0.99	6.76	6.69	6.69	53.18
8	7:00 AM	45	1	-56.36	0.55	1	0.55	6.76	3.75	3.75	-11.36
9	8:00 AM	45	1	-67.01	0.39	1	0.39	6.76	2.64	2.64	-22.01
10	9:00 AM	45	1	18.23	0.95	1	0.95	6.76	6.42	6.42	63.23
11	10:00 AM	45	1	-103.79	-0.24	1	-0.24	6.76	-1.61	1.61	-58.79
12	11:00 AM	45	1	-12.78	0.98	1	0.98	6.76	6.59	6.59	32.22
13	12:00 PM	45	1	-35.11	0.82	1	0.82	6.76	5.53	5.53	9.89
14	1:00 PM	45	1	-86.88	0.05	1	0.05	6.76	0.37	0.37	-41.88
15	2:00 PM	45	1	30.70	0.86	1	0.86	6.76	5.81	5.81	75.70
16	3:00 PM	45	1	-87.71	0.04	1	0.04	6.76	0.27	0.27	-42.71
17	4:00 PM	45	1	-34.16	0.83	1	0.83	6.76	5.59	5.59	10.84
18	5:00 PM	45	1	-13.73	0.97	1	0.97	6.76	6.57	6.57	31.27
19	6:00 PM	45	1	-103.23	-0.23	1	-0.23	6.76	-1.55	1.55	-58.23
20	7:00 PM	45	1	19.06	0.95	1	0.95	6.76	6.39	6.39	64.06
21	8:00 PM	45	1	-67.92	0.38	1	0.38	6.76	2.54	2.54	-22.92
22	9:00 PM	45	1	-55.42	0.57	1	0.57	6.76	3.84	3.84	-10.42
23	10:00 PM	45	1	7.27	0.99	1	0.99	6.76	6.71	6.71	52.27
24	11:00 PM	45	1	-108.41	-0.32	1	-0.32	6.76	-2.13	2.13	-63.41

Table E:4 Calculation Results Sheet No. 4 of Appendix E

Calculation for Experiment No.4 (15/7/2015)											
Time (hours)	No of hours	$\beta_1$	Length of pond side(m)	C1	x1y1	g, Mirror length(m)	SM1	B1(Rn)	G1	Abs U1	F1
1	12:00 AM	50	1	-78.61	0.20	1	0.20	6.77	1.34	1.34	-48.61
2	1:00 AM	50	1	-94.27	-0.07	1	-0.07	6.77	-0.50	0.50	-64.27
3	2:00 AM	50	1	0.36	1.00	1	1.00	6.77	6.77	6.77	30.36
4	3:00 AM	50	1	-39.61	0.77	1	0.77	6.77	5.22	5.22	-9.61
5	4:00 AM	50	1	-68.61	0.36	1	0.36	6.77	2.47	2.47	-38.61
6	5:00 AM	50	1	24.14	0.91	1	0.91	6.77	6.18	6.18	54.14
7	6:00 AM	50	1	-85.18	0.08	1	0.08	6.77	0.57	0.57	-55.18
8	7:00 AM	50	1	-19.09	0.95	1	0.95	6.77	6.40	6.40	10.91
9	8:00 AM	50	1	-19.75	0.94	1	0.94	6.77	6.37	6.37	10.25
10	9:00 AM	50	1	-84.73	0.09	1	0.09	6.77	0.62	0.62	-54.73
11	10:00 AM	50	1	24.44	0.91	1	0.91	6.77	6.16	6.16	54.44
12	11:00 AM	50	1	-69.21	0.36	1	0.36	6.77	2.40	2.40	-39.21
13	12:00 PM	50	1	-38.95	0.78	1	0.78	6.77	5.27	5.27	-8.95
14	1:00 PM	50	1	-0.27	1.00	1	1.00	6.77	6.77	6.77	29.73
15	2:00 PM	50	1	-94.14	-0.07	1	-0.07	6.77	-0.49	0.49	-64.14
16	3:00 PM	50	1	10.46	0.98	1	0.98	6.77	6.66	6.66	40.46
17	4:00 PM	50	1	-50.50	0.64	1	0.64	6.77	4.31	4.31	-20.50
18	5:00 PM	50	1	-58.38	0.52	1	0.52	6.77	3.55	3.55	-28.38
19	6:00 PM	50	1	17.17	0.96	1	0.96	6.77	6.47	6.47	47.17
20	7:00 PM	50	1	-91.48	-0.03	1	-0.03	6.77	-0.17	0.17	-61.48
21	8:00 PM	50	1	-8.16	0.99	1	0.99	6.77	6.70	6.70	21.84
22	9:00 PM	50	1	-30.80	0.86	1	0.86	6.77	5.82	5.82	-0.80
23	10:00 PM	50	1	-76.26	0.24	1	0.24	6.77	1.61	1.61	-46.26
24	11:00 PM	50	1	26.60	0.89	1	0.89	6.77	6.05	6.05	56.60

Table E:5 Calculation Results Sheet No. 5 of Appendix E

Calculation for Experiment No.5 (16/7/2015)											
Time (hours)	No of hours	$\beta_1$	Length of pond side(m)	C1	x1y1	g, Mirror length(m)	SM1	B1(Rn)	G1	Abs U1	F1
1	12:00 AM	55	1	-80.15	0.17	1	0.17	6.73	1.15	1.15	-65.15
2	1:00 AM	55	1	-68.68	0.36	1	0.36	6.73	2.45	2.45	-53.68
3	2:00 AM	55	1	22.07	0.93	1	0.93	6.73	6.23	6.23	37.07
4	3:00 AM	55	1	-64.48	0.43	1	0.43	6.73	2.90	2.90	-49.48
5	4:00 AM	55	1	-27.13	0.89	1	0.89	6.73	5.99	5.99	-12.13
6	5:00 AM	55	1	-4.16	1.00	1	1.00	6.73	6.71	6.71	10.84
7	6:00 AM	55	1	-78.41	0.20	1	0.20	6.73	1.35	1.35	-63.41
8	7:00 AM	55	1	14.48	0.97	1	0.97	6.73	6.51	6.51	29.48
9	8:00 AM	55	1	-48.83	0.66	1	0.66	6.73	4.43	4.43	-33.83
10	9:00 AM	55	1	-44.68	0.71	1	0.71	6.73	4.78	4.78	-29.68
11	10:00 AM	55	1	11.33	0.98	1	0.98	6.73	6.60	6.60	26.33
12	11:00 AM	55	1	-79.60	0.18	1	0.18	6.73	1.22	1.22	-64.60
13	12:00 PM	55	1	-0.10	1.00	1	1.00	6.73	6.73	6.73	14.90
14	1:00 PM	55	1	-31.47	0.85	1	0.85	6.73	5.74	5.74	-16.47
15	2:00 PM	55	1	-60.91	0.49	1	0.49	6.73	3.27	3.27	-45.91
16	3:00 PM	55	1	21.21	0.93	1	0.93	6.73	6.27	6.27	36.21
17	4:00 PM	55	1	-71.65	0.31	1	0.31	6.73	2.12	2.12	-56.65
18	5:00 PM	55	1	-17.26	0.95	1	0.95	6.73	6.43	6.43	-2.26
19	6:00 PM	55	1	-13.73	0.97	1	0.97	6.73	6.54	6.54	1.27
20	7:00 PM	55	1	-73.83	0.28	1	0.28	6.73	1.87	1.87	-58.83
21	8:00 PM	55	1	19.97	0.94	1	0.94	6.73	6.32	6.32	34.97
22	9:00 PM	55	1	-57.85	0.53	1	0.53	6.73	3.58	3.58	-42.85
23	10:00 PM	55	1	-35.01	0.82	1	0.82	6.73	5.51	5.51	-20.01
24	11:00 PM	55	1	3.12	1.00	1	1.00	6.73	6.72	6.72	18.12

## Appendix (F)

Table F:1 Calculation Results Sheet No. 1 of Appendix F

Calculation for Experiment No.1 (12/7/2015)								
Time (hours)	No of hours	B2	C2	Cos C2 (Deg.)	Abs U2	F2	Total Rn= U1+U2	E (mm/d)
1	12:00 AM	38.00	193.34	-0.97	6.56	128.66	13.13	7.97
2	1:00 AM	38.00	160.60	-0.94	6.36	161.40	12.72	7.67
3	2:00 AM	38.00	57.29	0.54	3.65	264.71	7.29	3.69
4	3:00 AM	38.00	194.35	-0.97	6.54	127.65	13.07	8.07
5	4:00 AM	38.00	102.71	-0.22	1.48	219.29	2.97	0.41
6	5:00 AM	38.00	113.75	-0.40	2.72	208.25	5.43	2.28
7	6:00 AM	38.00	183.28	-1.00	6.73	138.72	13.47	8.23
8	7:00 AM	38.00	48.89	0.66	4.44	273.11	8.87	4.74
9	8:00 AM	38.00	171.69	-0.99	6.67	150.31	13.35	8.14
10	9:00 AM	38.00	125.32	-0.58	3.90	196.68	7.80	3.93
11	10:00 AM	38.00	91.21	-0.02	0.14	230.79	0.28	2.06
12	11:00 AM	38.00	205.82	-0.90	6.07	116.18	12.14	6.65
13	12:00 PM	38.00	68.05	0.37	2.52	253.95	5.04	1.27
14	1:00 PM	38.00	149.00	-0.86	5.78	173.00	11.56	5.64
15	2:00 PM	38.00	147.99	-0.85	5.72	174.01	11.44	5.26
16	3:00 PM	38.00	69.01	0.36	2.42	252.99	4.83	0.82
17	4:00 PM	38.00	206.81	-0.89	6.02	115.19	12.04	5.71
18	5:00 PM	38.00	90.21	0.00	0.02	231.79	0.05	3.39
19	6:00 PM	38.00	126.32	-0.59	3.99	195.68	7.99	3.21
20	7:00 PM	38.00	170.68	-0.99	6.66	151.32	13.31	7.26
21	8:00 PM	38.00	49.46	0.65	4.38	272.54	8.77	4.38
22	9:00 PM	38.00	184.29	-1.00	6.73	137.71	13.45	8.23
23	10:00 PM	38.00	112.74	-0.39	2.61	209.26	5.21	1.97
24	11:00 PM	38.00	103.71	-0.24	1.60	218.29	3.20	0.59

Average Evaporation rate = 4.65 mm/day

Table F:2 Calculation Results Sheet No. 2 of Appendix F

Calculation for Experiment No.2 (13/7/2015)								
Time (hours)	No of hours	$\beta_2$	C2	Cos C2 (Deg.)	Abs U2	F2	Total Rn= U1+U2	E (mm/d)
1	12:00 AM	35	71.95	0.31	2.09	253.05	4.17	1.25
2	1:00 AM	35	102.62	-0.22	1.47	222.38	2.94	0.14
3	2:00 AM	35	189.59	-0.99	6.64	135.41	13.28	8.08
4	3:00 AM	35	58.32	0.53	3.54	266.68	7.07	3.32
5	4:00 AM	35	159.43	-0.94	6.30	165.57	12.61	7.56
6	5:00 AM	35	132.63	-0.68	4.56	192.37	9.12	4.89
7	6:00 AM	35	81.08	0.16	1.04	243.92	2.09	0.49
8	7:00 AM	35	208.97	-0.88	5.89	116.03	11.78	6.93
9	8:00 AM	35	76.92	0.23	1.52	248.08	3.05	0.22
10	9:00 AM	35	137.08	-0.73	4.93	187.92	9.86	5.45
11	10:00 AM	35	154.96	-0.91	6.10	170.04	12.20	6.94
12	11:00 AM	35	61.53	0.48	3.21	263.47	6.42	2.22
13	12:00 PM	35	193.96	-0.97	6.53	131.04	13.07	7.30
14	1:00 PM	35	98.25	-0.14	0.97	226.75	1.93	1.84
15	2:00 PM	35	114.85	-0.42	2.83	210.15	5.66	0.71
16	3:00 PM	35	177.28	-1.00	6.73	147.72	13.45	7.29
17	4:00 PM	35	52.74	0.61	4.08	272.26	8.15	2.62
18	5:00 PM	35	171.84	-0.99	6.66	153.16	13.33	6.88
19	6:00 PM	35	120.27	-0.50	3.39	204.73	6.79	2.19
20	7:00 PM	35	92.94	-0.05	0.34	232.06	0.69	2.78
21	8:00 PM	35	199.20	-0.94	6.36	125.80	12.72	6.72
22	9:00 PM	35	65.92	0.41	2.75	259.08	5.50	1.51
23	10:00 PM	35	149.49	-0.86	5.80	175.51	11.60	6.48
24	11:00 PM	35	142.54	-0.79	5.34	182.46	10.69	6.09
Average Evaporation rate = 4.16 mm/day								

Table F:3 Calculation Results Sheet No. 3 of Appendix F

Calculation for Experiment No.3 (14/7/2015)								
Time (hours)	No of hours	$\beta_2$	C2	Cos C2 (Deg.)	Abs U2	F2	Total Rn= U1+U2	E (mm/d)
1	12:00 AM	45	178.97	-1.00	6.76	136.03	13.52	3.98
2	1:00 AM	45	206.46	-0.90	6.05	108.54	12.10	2.90
3	2:00 AM	45	103.06	-0.23	1.53	211.94	3.05	4.61
4	3:00 AM	45	133.99	-0.69	4.69	181.01	9.39	0.79
5	4:00 AM	45	178.04	-1.00	6.76	136.96	13.51	3.98
6	5:00 AM	45	71.78	0.31	2.11	243.22	4.23	3.20
7	6:00 AM	45	188.18	-0.99	6.69	126.82	13.38	3.88
8	7:00 AM	45	123.64	-0.55	3.74	191.36	7.49	0.67
9	8:00 AM	45	112.99	-0.39	2.64	202.01	5.28	1.37
10	9:00 AM	45	198.23	-0.95	6.42	116.77	12.84	4.48
11	10:00 AM	45	76.21	0.24	1.61	238.79	3.22	4.49
12	11:00 AM	45	167.22	-0.98	6.59	147.78	13.18	1.19
13	12:00 PM	45	144.89	-0.82	5.53	170.11	11.06	1.47
14	1:00 PM	45	93.12	-0.05	0.37	221.88	0.74	11.50
15	2:00 PM	45	210.70	-0.86	5.81	104.30	11.63	3.08
16	3:00 PM	45	92.29	-0.04	0.27	222.71	0.54	10.63
17	4:00 PM	45	145.84	-0.83	5.59	169.16	11.19	3.92
18	5:00 PM	45	166.27	-0.97	6.57	148.73	13.13	2.42
19	6:00 PM	45	76.77	0.23	1.55	238.23	3.09	8.65
20	7:00 PM	45	199.06	-0.95	6.39	115.94	12.78	1.16
21	8:00 PM	45	112.08	-0.38	2.54	202.92	5.08	6.10
22	9:00 PM	45	124.58	-0.57	3.84	190.42	7.67	3.08
23	10:00 PM	45	187.27	-0.99	6.71	127.73	13.41	2.38
24	11:00 PM	45	71.59	0.32	2.13	243.41	4.27	3.16
Average Evaporation rate = 3.88 mm/day								

Table F:4 Calculation Results Sheet No. 4 of Appendix F

Calculation for Experiment No.4 (15/7/2015)								
Time (hours)	No of hours	$\beta_2$	C2	Cos C2 (Deg.)	Abs U2	F2	Total Rn= U1+U2	E (mm/d)
1	12:00 AM	50	101.39	-0.20	1.34	208.61	2.68	2.47
2	1:00 AM	50	85.73	0.07	0.50	224.27	1.01	3.02
3	2:00 AM	50	180.36	-1.00	6.77	129.64	13.54	6.43
4	3:00 AM	50	140.39	-0.77	5.22	169.61	10.43	3.38
5	4:00 AM	50	111.39	-0.36	2.47	198.61	4.94	0.76
6	5:00 AM	50	204.14	-0.91	6.18	105.86	12.36	4.49
7	6:00 AM	50	94.82	-0.08	0.57	215.18	1.14	3.98
8	7:00 AM	50	160.91	-0.94	6.40	149.09	12.80	4.82
9	8:00 AM	50	160.25	-0.94	6.37	149.75	12.75	4.07
10	9:00 AM	50	95.27	-0.09	0.62	214.73	1.24	4.61
11	10:00 AM	50	204.44	-0.91	6.17	105.56	12.33	3.05
12	11:00 AM	50	110.79	-0.35	2.40	199.21	4.81	2.62
13	12:00 PM	50	141.05	-0.78	5.26	168.95	10.53	0.98
14	1:00 PM	50	179.73	-1.00	6.77	130.27	13.54	2.55
15	2:00 PM	50	85.86	0.07	0.49	224.14	0.98	6.93
16	3:00 PM	50	190.46	-0.98	6.66	119.54	13.32	1.68
17	4:00 PM	50	129.50	-0.64	4.31	180.50	8.61	1.16
18	5:00 PM	50	121.62	-0.52	3.55	188.38	7.10	2.31
19	6:00 PM	50	197.17	-0.96	6.47	112.83	12.94	2.10
20	7:00 PM	50	88.52	0.03	0.18	221.48	0.35	6.69
21	8:00 PM	50	171.84	-0.99	6.70	138.16	13.41	3.86
22	9:00 PM	50	149.20	-0.86	5.82	160.80	11.63	2.53
23	10:00 PM	50	103.74	-0.24	1.61	206.26	3.22	3.12
24	11:00 PM	50	206.60	-0.89	6.06	103.40	12.11	4.32
Average Evaporation rate = 3.41 mm/day								

Table F:5 Calculation Results Sheet No. 5 of Appendix F

Calculation for Experiment No.5 (16/7/2015)								
Time (hours)	No of hours	$\beta_2$	C2	Cos C2 (Deg.)	Abs U2	F2	Total Rn= U1+U2	E (mm/d)
1	12:00 AM	55	99.85	-0.17	1.15	205.15	2.30	3.40
2	1:00 AM	55	111.32	-0.36	2.45	193.68	4.89	1.41
3	2:00 AM	55	202.07	-0.93	6.24	102.93	12.47	2.97
4	3:00 AM	55	115.52	-0.43	2.90	189.48	5.80	0.71
5	4:00 AM	55	152.87	-0.89	5.99	152.13	11.98	3.06
6	5:00 AM	55	175.84	-1.00	6.71	129.16	13.42	4.17
7	6:00 AM	55	101.59	-0.20	1.35	203.41	2.70	4.05
8	7:00 AM	55	194.48	-0.97	6.51	110.52	13.03	3.87
9	8:00 AM	55	131.17	-0.66	4.43	173.83	8.86	0.81
10	9:00 AM	55	135.32	-0.71	4.78	169.68	9.57	1.22
11	10:00 AM	55	191.33	-0.98	6.60	113.67	13.19	2.56
12	11:00 AM	55	100.40	-0.18	1.21	204.60	2.43	7.63
13	12:00 PM	55	179.90	-1.00	6.73	125.10	13.46	0.82
14	1:00 PM	55	148.53	-0.85	5.74	156.47	11.48	1.66
15	2:00 PM	55	119.09	-0.49	3.27	185.91	6.54	6.41
16	3:00 PM	55	201.21	-0.93	6.27	103.79	12.55	0.13
17	4:00 PM	55	108.35	-0.31	2.12	196.65	4.23	8.18
18	5:00 PM	55	162.74	-0.95	6.42	142.26	12.85	0.60
19	6:00 PM	55	166.27	-0.97	6.54	138.73	13.07	0.53
20	7:00 PM	55	106.17	-0.28	1.87	198.83	3.75	5.67
21	8:00 PM	55	199.97	-0.94	6.32	105.03	12.65	1.16
22	9:00 PM	55	122.15	-0.53	3.58	182.85	7.16	2.08
23	10:00 PM	55	144.99	-0.82	5.51	160.01	11.02	1.85
24	11:00 PM	55	183.12	-1.00	6.72	121.88	13.44	3.70
Average Evaporation rate = 2.86 mm/day								

Table F:7 Calculation Results Sheet No. 7of Appendix F

Calculation for Experiment No.7(18/7/2015)										
Time (hours)	No of hours	B2	Length of pond side(m)	C2	a, Mirror length(m)	Cos C2 (Deg.)	Abs U2	F2	Total Rn	E (mm/d)
1	12:00 AM	55	1	171.19	1	-0.99	6.64	133.81	6.64	0.22
2	1:00 AM	55	1	181.19	1	-1.00	6.72	123.81	6.72	1.03
3	2:00 AM	55	1	132.84	1	-0.68	4.57	172.16	4.57	0.59
4	3:00 AM	55	1	147.40	1	-0.84	5.66	157.60	5.66	0.52
5	4:00 AM	55	1	172.35	1	-0.99	6.66	132.65	6.66	0.99
6	5:00 AM	55	1	119.69	1	-0.50	3.33	185.31	3.33	2.28
7	6:00 AM	55	1	175.17	1	-1.00	6.69	129.83	6.69	0.26
8	7:00 AM	55	1	143.64	1	-0.81	5.41	161.36	5.41	1.08
9	8:00 AM	55	1	136.13	1	-0.72	4.84	168.87	4.84	3.02
10	9:00 AM	55	1	179.77	1	-1.00	6.72	125.23	6.72	1.61
11	10:00 AM	55	1	121.42	1	-0.52	3.50	183.58	3.50	4.79
12	11:00 AM	55	1	165.47	1	-0.97	6.50	139.53	6.50	3.27
13	12:00 PM	55	1	155.42	1	-0.91	6.11	149.58	6.11	2.82
14	1:00 PM	55	1	126.80	1	-0.60	4.02	178.20	4.02	5.14
15	2:00 PM	55	1	182.29	1	-1.00	6.71	122.71	6.71	3.87
16	3:00 PM	55	1	127.78	1	-0.61	4.12	177.22	4.12	4.32
17	4:00 PM	55	1	153.98	1	-0.90	6.04	151.02	6.04	4.38
18	5:00 PM	55	1	166.79	1	-0.97	6.54	138.21	6.54	3.99
19	6:00 PM	55	1	120.94	1	-0.51	3.45	184.06	3.45	5.57
20	7:00 PM	55	1	179.09	1	-1.00	6.72	125.91	6.72	2.36
21	8:00 PM	55	1	137.43	1	-0.74	4.95	167.57	4.95	2.94
22	9:00 PM	55	1	142.24	1	-0.79	5.31	162.76	5.31	1.15
23	10:00 PM	55	1	176.14	1	-1.00	6.70	128.86	6.70	0.10
24	11:00 PM	55	1	119.83	1	-0.50	3.34	185.17	3.34	2.27

Average Evaporation rate = 2.44mm/day

Table F:8 Calculation Results Sheet No. 8of Appendix F

Calculation for Experiment No.8(19/7/2015)										
Time (hours)	No of hours	B2	Length of pond side(m)	C2	a, Mirror length(m)	Cos C2 (Deg.)	Abs U2	F2	Total Rn	E (mm/d)
1	12:00 AM	50	1	165.65	1	-0.97	6.48	144.35	6.48	1.71
2	1:00 AM	50	1	166.08	1	-0.97	6.49	143.92	6.49	1.70
3	2:00 AM	50	1	127.23	1	-0.60	4.04	182.77	4.04	3.55
4	3:00 AM	50	1	153.76	1	-0.90	6.00	156.24	6.00	0.81
5	4:00 AM	50	1	151.61	1	-0.88	5.88	158.39	5.88	0.90
6	5:00 AM	50	1	128.35	1	-0.62	4.15	181.65	4.15	2.21
7	6:00 AM	50	1	166.57	1	-0.97	6.50	143.43	6.50	0.42
8	7:00 AM	50	1	132.18	1	-0.67	4.49	177.82	4.49	2.38
9	8:00 AM	50	1	145.80	1	-0.83	5.53	164.20	5.53	1.58
10	9:00 AM	50	1	158.92	1	-0.93	6.24	151.08	6.24	1.05
11	10:00 AM	50	1	125.41	1	-0.58	3.87	184.59	3.87	3.68
12	11:00 AM	50	1	163.59	1	-0.96	6.41	146.41	6.41	3.44
13	12:00 PM	50	1	139.17	1	-0.76	5.06	170.83	5.06	3.62
14	1:00 PM	50	1	137.91	1	-0.74	4.96	172.09	4.96	5.38
15	2:00 PM	50	1	164.31	1	-0.96	6.44	145.69	6.44	5.53
16	3:00 PM	50	1	125.68	1	-0.58	3.90	184.32	3.90	6.19
17	4:00 PM	50	1	157.80	1	-0.93	6.19	152.20	6.19	5.29
18	5:00 PM	50	1	147.15	1	-0.84	5.62	162.85	5.62	5.73
19	6:00 PM	50	1	131.19	1	-0.66	4.40	178.81	4.40	4.97
20	7:00 PM	50	1	166.74	1	-0.97	6.51	143.26	6.51	2.53
21	8:00 PM	50	1	129.12	1	-0.63	4.22	180.88	4.22	3.42
22	9:00 PM	50	1	150.29	1	-0.87	5.81	159.71	5.81	1.37
23	10:00 PM	50	1	155.02	1	-0.91	6.06	154.98	6.06	0.76
24	11:00 PM	50	1	126.67	1	-0.60	3.99	183.33	3.99	1.49

Average Evaporation rate = 2.9mm/day

Table F:9 Calculation Results Sheet No. 9 of Appendix F

Calculation for Experiment No.9(20/7/2015)										
Time (hours)	No of hours	B2	Length of pond side(m)	C2	a, Mirror length(m)	Cos C2 (Deg.)	Abs U2	F2	Total Rn	E (mm/d)
1	12:00 AM	45	1	150.95	1	-0.87	5.83	164.05	5.83	1.09
2	1:00 AM	45	1	149.51	1	-0.86	5.74	165.49	5.74	0.29
3	2:00 AM	45	1	131.12	1	-0.66	4.38	183.88	4.38	1.32
4	3:00 AM	45	1	147.27	1	-0.84	5.61	167.73	5.61	1.69
5	4:00 AM	45	1	141.03	1	-0.78	5.18	173.97	5.18	2.01
6	5:00 AM	45	1	134.32	1	-0.70	4.66	180.68	4.66	4.15
7	6:00 AM	45	1	150.86	1	-0.87	5.82	164.14	5.82	2.40
8	7:00 AM	45	1	132.53	1	-0.68	4.50	182.47	4.50	3.39
9	8:00 AM	45	1	143.76	1	-0.81	5.37	171.24	5.37	1.87
10	9:00 AM	45	1	144.89	1	-0.82	5.45	170.11	5.45	1.81
11	10:00 AM	45	1	131.95	1	-0.67	4.45	183.05	4.45	2.41
12	11:00 AM	45	1	150.61	1	-0.87	5.81	164.39	5.81	3.27
13	12:00 PM	45	1	135.25	1	-0.71	4.73	179.75	4.73	3.22
14	1:00 PM	45	1	139.84	1	-0.76	5.09	175.16	5.09	4.68
15	2:00 PM	45	1	148.15	1	-0.85	5.66	166.85	5.66	5.11
16	3:00 PM	45	1	130.98	1	-0.66	4.37	184.02	4.37	5.23
17	4:00 PM	45	1	148.82	1	-0.86	5.70	166.18	5.70	5.08
18	5:00 PM	45	1	138.85	1	-0.75	5.02	176.15	5.02	5.60
19	6:00 PM	45	1	136.10	1	-0.72	4.80	178.90	4.80	4.89
20	7:00 PM	45	1	150.29	1	-0.87	5.79	164.71	5.79	4.16
21	8:00 PM	45	1	131.56	1	-0.66	4.42	183.44	4.42	4.32
22	9:00 PM	45	1	145.80	1	-0.83	5.51	169.20	5.51	1.76
23	10:00 PM	45	1	142.78	1	-0.80	5.31	172.22	5.31	1.49
24	11:00 PM	45	1	133.11	1	-0.68	4.55	181.89	4.55	2.06

Average Evaporation rate = 3.05 mm/day

Table F:10 Calculation Results Sheet No. 10 of Appendix F

Calculation for Experiment No.10(21/7/2015)										
Time (hours)	No of hours	B2	Length of pond side(m)	C2	a, Mirror length(m)	Cos C2 (Deg.)	Abs U2	F2	Total Rn	E (mm/d)
1	12:00 AM	38	1	133.05	1	-0.68	4.53	188.95	4.53	2.12
2	1:00 AM	38	1	133.62	1	-0.69	4.58	188.38	4.58	1.22
3	2:00 AM	38	1	134.97	1	-0.71	4.69	187.03	4.69	1.13
4	3:00 AM	38	1	132.76	1	-0.68	4.50	189.24	4.50	1.27
5	4:00 AM	38	1	134.77	1	-0.70	4.67	187.23	4.67	2.02
6	5:00 AM	38	1	133.93	1	-0.69	4.60	188.07	4.60	2.07
7	6:00 AM	38	1	133.20	1	-0.68	4.54	188.80	4.54	2.11
8	7:00 AM	38	1	135.15	1	-0.71	4.70	186.85	4.70	1.99
9	8:00 AM	38	1	132.92	1	-0.68	4.52	189.08	4.52	2.13
10	9:00 AM	38	1	134.36	1	-0.70	4.64	187.64	4.64	2.48
11	10:00 AM	38	1	134.40	1	-0.70	4.64	187.60	4.64	3.35
12	11:00 AM	38	1	132.90	1	-0.68	4.52	189.10	4.52	3.44
13	12:00 PM	38	1	135.14	1	-0.71	4.70	186.86	4.70	3.30
14	1:00 PM	38	1	133.24	1	-0.68	4.54	188.76	4.54	5.16
15	2:00 PM	38	1	133.89	1	-0.69	4.60	188.11	4.60	5.12
16	3:00 PM	38	1	134.80	1	-0.70	4.68	187.20	4.68	4.19
17	4:00 PM	38	1	132.76	1	-0.68	4.50	189.24	4.50	6.06
18	5:00 PM	38	1	134.95	1	-0.71	4.69	187.05	4.69	5.93
19	6:00 PM	38	1	133.67	1	-0.69	4.58	188.33	4.58	6.87
20	7:00 PM	38	1	133.43	1	-0.69	4.56	188.57	4.56	6.02
21	8:00 PM	38	1	135.08	1	-0.71	4.70	186.92	4.70	5.05
22	9:00 PM	38	1	132.81	1	-0.68	4.51	189.19	4.51	4.32
23	10:00 PM	38	1	134.60	1	-0.70	4.66	187.40	4.66	3.33
24	11:00 PM	38	1	134.14	1	-0.70	4.62	187.86	4.62	2.49

Average Evaporation rate = 3.46 mm/day

Table F:11 Calculation Results Sheet No. 11of Appendix F

Calculation for Experiment No.11(22/7/2015)										
Time (hours)	No of hours	B2	Length of pond side(m)	C2	a, Mirror length(m)	Cos C2 (Deg.)	Abs U2	F2	Total Rn	E (mm/d)
1	12:00 AM	35	1	141.62	1	-0.78	5.21	183.38	5.21	2.85
2	1:00 AM	35	1	136.06	1	-0.72	4.79	188.94	4.79	1.68
3	2:00 AM	35	1	119.40	1	-0.49	3.26	205.60	3.26	2.85
4	3:00 AM	35	1	143.24	1	-0.80	5.32	181.76	5.32	2.26
5	4:00 AM	35	1	123.78	1	-0.56	3.69	201.22	3.69	1.52
6	5:00 AM	35	1	129.37	1	-0.63	4.22	195.63	4.22	2.12
7	6:00 AM	35	1	140.21	1	-0.77	5.11	184.79	5.11	2.43
8	7:00 AM	35	1	118.22	1	-0.47	3.14	206.78	3.14	3.94
9	8:00 AM	35	1	140.88	1	-0.78	5.16	184.12	5.16	2.39
10	9:00 AM	35	1	128.37	1	-0.62	4.13	196.63	4.13	3.18
11	10:00 AM	35	1	124.63	1	-0.57	3.78	200.37	3.78	4.96
12	11:00 AM	35	1	142.92	1	-0.80	5.30	182.08	5.30	2.78
13	12:00 PM	35	1	119.01	1	-0.48	3.22	205.99	3.22	4.38
14	1:00 PM	35	1	136.97	1	-0.73	4.86	188.03	4.86	6.12
15	2:00 PM	35	1	133.38	1	-0.69	4.56	191.62	4.56	7.35
16	3:00 PM	35	1	120.86	1	-0.51	3.41	204.14	3.41	6.24
17	4:00 PM	35	1	143.70	1	-0.81	5.36	181.30	5.36	7.74
18	5:00 PM	35	1	121.66	1	-0.52	3.49	203.34	3.49	9.18
19	6:00 PM	35	1	132.16	1	-0.67	4.46	192.84	4.46	7.43
20	7:00 PM	35	1	138.04	1	-0.74	4.94	186.96	4.94	8.06
21	8:00 PM	35	1	118.64	1	-0.48	3.18	206.36	3.18	7.41
22	9:00 PM	35	1	142.42	1	-0.79	5.27	182.58	5.27	4.81
23	10:00 PM	35	1	125.72	1	-0.58	3.88	199.28	3.88	4.87
24	11:00 PM	35	1	127.18	1	-0.60	4.02	197.82	4.02	3.77

Average Evaporation rate = 4.59 mm/day