ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

MODELING AND SIMULATION OF SOLAR EVAPORATIVE CRYSTALLIZATION OF LAKE BRINE (THE CASE OF LAKE ABIJATA/SHALLA)

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ADDIS ABABA UNIVERSITY
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"MODELING AND SIMULATION OF SOLAR EVAPORATIVE CRYSTALLIZATION OF LAKE BRINE"
(THE CASE OF LAKE ABIJATA/SALLA)

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Abstract

Abijata Lake water constitutes the raw material for the production of salt in solar salt works. The salts are:

Industrial salts------Sodium carbonate (Na_2CO_3)

Edible salt-----------Sodium chloride (NaCl)

The concentration of the Lake water through solar evaporation results in the successive crystallization of less soluble salts (Na_2CO_3, NaHCO3) first, followed by NaCl. Salt work uses the empirical Baume (^{O}Be) Scale, to measure the concentration of the brines. According to that scale the Lake water concentration is 4.22 ^{O}Be (specific gravity of 1.03).The crystallization of Trona (Na_2CO_3.NaHCO3.2H_2O) begins at 26.13 ^{O}Be (specific gravity of 1.22) and sodium chloride (NaCl) crystallize at 39.16 ^{O}Be (specific gravity of 1.37)

Solar crystallization Processes

Producing salt from the lake water involves the selective recovery of pure Trona (Na_2CO_3.NaHCO3.2H_2O) and sodium chloride (NaCl), free of other soluble or non-soluble salts and other substances. To this end, an appropriate quantity of Lake Water is concentrated through natural evaporation, which leads to the fractional crystallization of all salts contained: a process based on their varying solubility. The basic step in the processes of salt recovery from the Lake water was made with the division of the evaporation basins in to two:

The first basin, usually called nurse pond (pre-concentration pond), was used for the production of saturated brine, which was feed in to second basin, usually called crystallizer.

What basically elevates Salt works to ecosystem is the fact for Lake Water to be concentrated up to the point salt crystallization. 90% of its salt content has to be evaporate, thus requires a vast surface. For this reason ponds (pre-concentration ponds) take up 90% of the salt work area. Crystallizers take up approximately 10% of the salt work area. Crystallizes take up the remaining 10% of the area. These basins are especially designed and have their bottom leveled and concentrated, aiming to facilitate and optimize the collection of salt with machinery.

The first pond of the salt work is feed with Lake Water (raw material) usually via pumping. As the lake water flows along the pond, its concentration raises continuously through natural evaporation. The evaporation (concentration) of brine is achieved by exposure to solar radiation and with the help of the prevailing microclimate in the area, especially the winds, rainfall, air temperature and humidity and duration of sunshine. So an increasing salinity (concentration) gradient is created throughout the ponds of the salt works with a simultaneous and continuous reduction of the volume of Lake Water, which initially entered the system of ponds. This is the physicochemical process of salt production.

CHAPTER ONE

INTRODUCTION

1.1 Background

One of the popular methods for production of ***soda ash (sodium carbonate: Na_2CO_3)*** is **calcination** of ***Trona: $Na_2CO_3.NaHCO_3.2H_2O$***, where Trona is treated at high temperature (350-400^{O}C) to remove water of crystallization and to decompose the bicarbonate. The thesis deals with the production of Trona using solar evaporative crystallization of Abijata or Shalla lake brine. The lake brine is rich in sodium carbonate, sodium bicarbonate and sodium chloride and small amounts of sodium sulfate with traces of other materials and some impurities. Even though the lake is rich in the above chemical species it is very dilute, with about 99% water. In order to remove this percentage of water by evaporation it is energy intensive, so solar energy is the best alternative. Impurities are removed by fractional crystallization.

In order to get the desired solid, two steps are carried out:

1. ***Pre-concentration by evaporation in pre-concentration pond***

2. ***Evaporative crystallization in Trona crystallization pond.***

This thesis concentrates on the **evaporative crystallization** process.

In Abijata Soda Ash Enterprise the operating principles of the solar pond is not clearly known and the same to the efficiency of the pond. Lack of knowledge, in the operating principles of solar pond, results in poor quality of the desired crystal (i.e. co-crystallization of impurities). This problem can be extended to solar salt production, for example ***Afdera*** in the Afar region.

Thus, the thesis is aimed at modeling and simulation of Trona crystallization pond and conducting experimental investigation in the site using ***artificial evaporation pans*** having different depths.

1.2 Objectives

The general objective of the project is to model and simulate evaporative crystallization of Trona pond and to characterize its operating conditions (i.e. brine concentration, brine depth and energy storage).

The specific objectives are

- Modeling and simulation of the crystallization pond,
- Characterization of operating conditions,
- Experimental investigation of evaporation rate
- Experimental investigation temperature distribution of the brine in different depth and concentration

1.3 Methodology

The methodology is primarily based on the appropriate model development of the system, which represents the actual activities. The models are produced in the workshop.

Data collection is a primary activity next to model building. The data is collected in the site, Abijata, near Zeway and the collected data should be analyzed. Details of the methodology of the research are described in chapter three.

1.4 Summery of Previous Research and Research gap

Even though a number of research works have been conducted in the area of solar evaporation crystallization, research has not been done in this case. Except for the pilot plant project study of soda ash, there is no other research work. This is the reason for the Abijata Soda Ash Enterprise to be still in the pilot plant stage.

This thesis work will contribute to fill the gape in the research work and will initiate others to work in the area.

CHAPTER TWO

LITERATURE REVIEW

Contrary to this case, a lot has been done in solar evaporative of lake (sea) water for production of valuable chemicals for industrial and house hold use. All of these have an input for solar evaporative crystallization of Lake Abijata for production of Trona. These include:

- Physical chemistry of lake brine (solution)
- Principle of evaporation
- Parameters determining evaporation rate
- Heat transfer in ponds

2.1 Physical Chemistry of Lake Brine Solution

2.1.1 Properties of the Lake Brine (Solution)

The lake is rich in the following chemical species: Na_2CO_3, $NaHCO_3$, NaCl and other chemical species in small amount. The chemical analysis of the lake brine shows the following results.

Table 2.1 Abijata lake water (brine) chemical composition (w/w %)

Chemical species	**High concentration**	**Low concentration**
Na_2CO_3	*0.88*	*1.27*
$NaHCO_3$	*0.88*	*0.56*
NaCl	*0.62*	*0.51*
Na_2SO_4	*0.033*	*0.021*
NaF	*0.044*	*0.03*
SiO_2	*0.033*	*0.023*
H_2O	*97.9*	*98.5*
Sp.gr	*1.017*	*1.01*

Therefore, it is possible to produce valuable industrial products using the solubility characteristics and relative composition of the chemical species present in the lake brine such as sodium carbonate (Na_2CO_3, $Na_2CO_3.H_2O$, $Na_2CO_3.7H_2O$,$Na_2CO_3.10H_2O$), sodium bicarbonate ($NaHCO_3$) Trona (Na_2CO_3. $NaHCO_3.2H_2O$) and sodium chloride (NaCl).

The chemical composition of the lake brine is very dilute, with almost 98% water. To get the desired valuable chemical products, increasing the concentration is inevitable, which leads to evaporation process (i.e. removal of some amount of water). The evaporation process is energy intensive. The high-energy requirement of the evaporation process, in addition to the dilute lake brine, needs easy and cheep energy source for the production of the desired product.

Using the evaporation process, it is possible to extract the following chemical species

Table 2.2 Chemical compounds that can be obtained from Lake Abijata

Chemical compounds	**Name**
Na_2CO_3	Anhydrous sodium carbonate
$NaHCO_3$	Sodium bicarbonate
NaCl	Sodium chloride
$Na_2CO_3.H_2O$	Sodium carbonate mono hydrate
$Na_2CO_3.7H_2O$	Sodium carbonate hepta-hydrate
$Na_2CO_3.10H_2O$	Sodium carbonate deca-hydrate
Na_2CO_3. $NaHCO_3.2H_2O$	Trona

according to their solubility difference. It is possible also to separate Na_2 SO_4, but the concentration is insignificant. Solid-liquid separation based on the solubility difference is known as fractional crystallization.

Before the crystallization process, the lake brine has to be evaporated using the evaporation process. As the energy required for this process is high, the cheep energy source will be solar energy.

Salt production has been made by solar evaporation for thousands of years, but the evaporation process has become properly understood only during this centaury. The evaporation process needs large area since the lake is very dilute. So in order to mitigate this problem use of artificial pond is the best alternative.

Pre-concentration: this is the evaporation process before crystallization is initiated. Initially the lake water is concentrated by solar evaporation from about 1% total alkali to about 12% total alkali, until the Trona crystallization point the 'Trona point'. As the evaporation proceeds, the remaining brine becomes more- and more- concentrated and part of the bi-carbonate decomposes according to the following equilibrium reaction

$$HCO_3^- + H^+ \rightleftarrows H_2CO_3$$
$$H_2CO_3 \leftrightarrows H_2O + CO_2(aq)$$
$$CO_2(aq) \rightleftarrows CO_2(g) \qquad 2.1$$
$$HCO_3^- \rightleftarrows H^+ + CO_3^-$$
$$2Na^+ \rightleftarrows 2Na^+$$

Overall reaction

$$2NaHCO_3 \rightleftarrows Na_2CO_3 + H_2O + CO_2(g) \qquad 2.2$$

Because of bicarbonate decomposition the bicarbonate ratio increases from 1.4 at the lake brine to about 3 at the Trona point and carbon dioxide evolution takes place. The remaining bicarbonate is removed down stream as Trona at the Trona ponds.

The specific gravity is a very useful indicator in following up the brine concentration. The specific gravity increases from about 1.015 g/cm^3 (2.4Be`) to about 1.22 g/cm$^3$ (26 Be`) at the Trona point.

The concentration scale used in salt production is the Baume` scale (^{O} Be) based on the brine specific density, determined suitable for fluid heavier than water and reported to a temperature of 60^{O}F, 15.5 ^{O}C:

$$\text{Specific gravity (sp.gr)} = 145 \big/ \left(145 - {}^{o}Be\right)$$

$$ {}^{o}Be = 145 - \frac{145}{sp.gr} \qquad 2.3$$

where specific density represents the ratio between the density of the solution and the density of water at the same temperature

2.1.2 Phase Relation

To throughtly understand the operation of solar pond, it is necessary to know the physical chemistry that occures during brine evaporation, both in the crysallization phase relationship and the kinetics of rates of crystallization and evaporation. The genaralities of lake water evaporation path are well konown, although surprizingly, the specific performane is less defined.

A phase diagram of the lake brine main component $Na_2CO_3 : NaHCO_3 : NaCl : H_2O$ well describes the crystallization process. The evaporation pond system is characterized by very slow dynamics. The average retention time for the pond varies from several weeks to months, for example it extends over more than three months, for the pre-concentration ponds, and about three weeks for the Trona ponds. Human operators will carry out the process control for the evaporation pond system. Fig 2.1 shows the phase diagram of Trona at the given temperature.

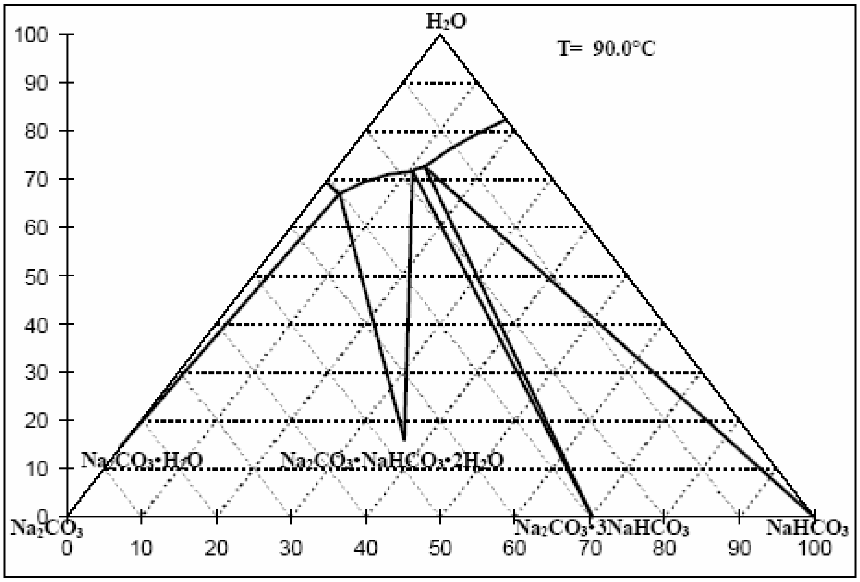


Fig 2.1 Ternary solubility diagram for sodium carbonate-bicarbonate at 90O, the units are in weight percent

After running in periods the evaporation pond system is controlled by monitoring periodically the brine, specific gravity, total alkali, temperature, and some samples for chemical analysis

Fig 2.1 represents the composition of a ternary system on a triangular diagram. The apex of the triangle represents the pure component Na_2CO_3, $NaHCO_3$ and H_2O. A point on the side of the triangle stands for a binary system: Na_2CO_3- H_2O, Na_2CO_3-$NaHCO_3$ $NaHCO_3$- H_2O. A point within the triangle represents a ternary system Na_2CO_3-$NaHCO_3$- H_2O.

On the left side of the figure Na_2CO_3 forms a hydrate that is $Na_2CO_3.H_2O$ (sodium carbonate mono-hydrate) at the given temperature while sodium bi-carbonate is not hydrated at the given temperature. Other points on the left and right side of the triangle are the solubility of the salts Na_2CO_3 and $NaHCO_3$ respectively. There are points inside and in the lower side of the triangle, which indicates where $Na_2CO_3.NaHCO_3.H_2O$ (Trona) and Na_2CO_3-3$NaHCO_3$ are crystallized, respectively.

2.1.3 Sequence of Crystallization

Due to its solubility, Trona ($Na_2CO_3.NaHCO_3.2H_2O$) is first to be crystallized. Then the mother liquor will be rich in carbonate, which paves the way for crystallization of sodium carbonate. Finally, the brine rich in sodium carbonate will give one of the following outputs based on the process control and temperature difference:

Table 2.3 Compounds crystallized from the mother liquor

Chemical compound	**Name**
$Na_2CO_3.10H_2O$	Sodium carbonate deca-hydrate
$Na_2CO_3.7H_2O$	Sodium carbonate hepta-hydrate
$Na_2CO_3.H_2O$	Sodium carbonate mono-hydrate

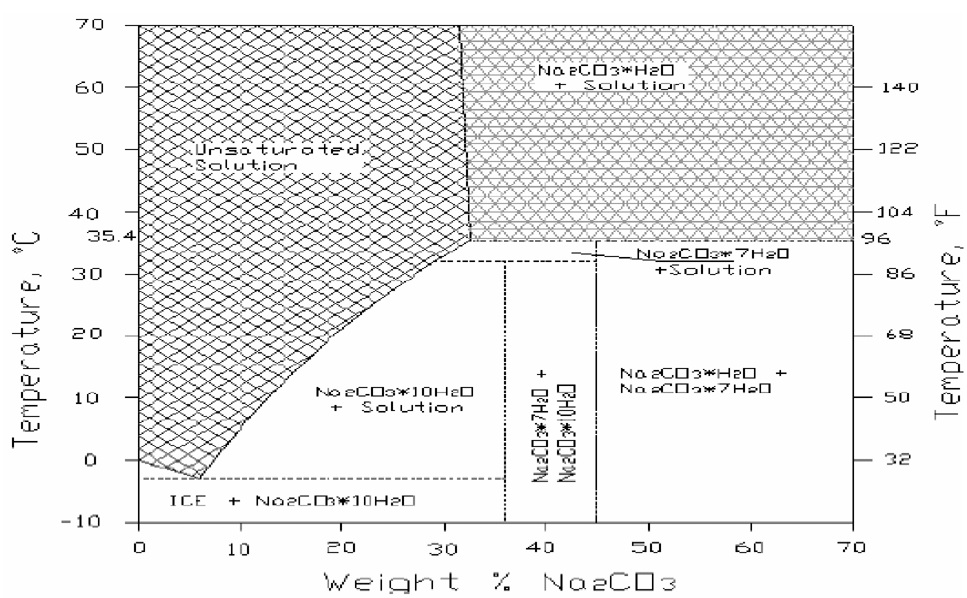


Fig 2.2 Phase diagram of sodium carbonate-water system

The remaining amount of sodium carbonate with small amounts of bicarbonate will also give Trona. After this, the last brine will be rich in sodium chloride with further evaporation it gives common salt. Further washing and purification is necessary to make it edible.

From fig 2.2 illustrates that sodium carbonate is readily soluble in water. It reaches maximum solubility at the relatively low temperature of 35.4°C (95.7°F). At this point, 100 parts of water dissolves 49.7 parts of Na_2CO_3 to yield a 33.2% solution by weight. Solubility decreases above this temperature

Fig 2.2 also helps to trace the effects of cooling, heating and changing concentrations. For example, a 20% Na_2CO_3 solution is unsaturated at all temperatures above 22.4°C (72.3°F), which is where the 20% concentration line crosses the saturation curve. Below this temperature, the solid phase ($Na_2CO_3 \bullet 10H_2O$) begins to form, increasing in amount as temperature falls. This phase change causes the concentration of the saturated solution in contact with the crystals to decrease, until at -2.1°C (28.2°F), the liquid phase disappears leaving only a mixture of solid $Na_2CO_3 \bullet 10H_2O$ and ice.

2.1.4 Solution and Solubility

A solution is a homogeneous mixture of two or more substances. The constituents of liquid solutions are frequently called solute and solvent. The solubility characteristics of a solute in a given solvent have a considerable influence in the choice of a method of crystallization. It would be useless, for instance, to cool a hot saturated solution of sodium chloride in the hope of depositing crystals in any quantity. The same is true for the Abijata lake brine. A reasonable yield could only be achieved by removing some of the water by evaporation, and this is what is done in practice. On the other hand, a direct cooling crystallization operation would be for the salt such as sodium carbonate deca-hydrate. The solubility curve of sodium carbonate is very steep. This makes it a very appropriate system for cooling crystallization process. As a standard sodium carbonate solution at 33 ^{O}C is cooled to 15^{O}C for each 100 gm of saturated solution about 40 gm of sodium carbonate deca-hydrate precipitates leaving a dilute solution that becomes under saturated as it is warmed back to 33 ^{O}C.

Not all solubility curve are smooth, a discontinuity in solubility curve denotes a phase change. The general trend of solubility can be predicted from Lechatelier's Principle which, for the present purpose, can be stated: when a system in equilibrium is subjected to a change in temperature or pressure, the system will adjust itself to a new equilibrium state in order to receive the effect of the change. Most solutes dissolve in their near-saturated solutions with an absorption of heat (endothermic heat of solution) and an increase in temperature results in an increase in solubility. An inverted solubility effect occurs when the solute dissolves in its near-saturated solution with an evolution of heat (exothermic heat of solution).

Strictly speaking, solubility is also a function of pressure, but the effect is generally negligible in the system normally encountered in crystallization from solution.

2.1.5 Theoretical Crystal Yield

If the solubility data for a substance in a particular solvent are known, calculating the maximum yield of pure crystals that could be obtained by cooling or evaporating a given solution is an easy task. The yield will refer only to the quantity of pure crystal deposited from the solution. However the actual yield of solid material may be slightly higher than that calculated, because crystal masses invariably retain some mother liquor even after filtration. When the crystals are dried, they become coated with a layer of material that is frequently of a lower grade than in the bulk of the crystals. Impure dry crystal masses produced commercial are very often the result of inadequate mother liquor removal. The calculation of the yield for the case of crystallization by cooling is quite straight forward if the initial concentration and the solubility of the substance at the lower temperature are known. The calculation can be complicated slightly if some of the solvent is lost deliberately or accidentally during the cooling process, or if the substance itself removes some of the solvent, e.g. by taking up water of crystallization. All this possibilities are taken into account in the following equations, which may be used to calculate the maximum yield of pure crystals under a variety of conditions.

Let

C_1 = initial solution concentration $\left[kg\ anhydrous\ salt \big/ kg\ solvent \right]$

C_2 = final solution concentration $\left[kg\ anhydrous\ salt \big/ kg\ solvent \right]$

W = initial mass of the solvent $[kg]$

V = solvent lost by evaporation $[kgperkgofo\ riginalsol\ vent]$

R = ratio of molar masses of hydrate and anhydrous salt $[-]$

Y = Crystal yield [kg]

Substances crystallize un-solvated (e.g anhydrous salt)

Total loss of solvent: $Y = WC_1$

No loss of solvent: $Y = W(C_1 - C_2)$ 2.4

Substances crystallize as a solvate

Total loss of free solvent: $Y = WRC_1$

No loss of solvent: $$Y = \frac{WR(C_1 - C_2)}{1 - C_2(R-1)}$$

Partial loss of solvent: $$Y = \frac{WR[C_1 - C_2(1-V)]}{1 - C_2(R-1)} \qquad 2.5$$

The last equation can be used as the general equation for all cases.

2.1.6 Density

The densities of most pure solid substances are readily available in standard physical property handbooks. The density of actual crystallized substances, however, may differ from literature values because of the presence of vapor or liquid inclusion or adhering surface moisture.

Solid densities have very small temperature dependence, but this can be ignored for industrial crystallization purpose.

It is often possible to estimate to ± 5% the density of a solution from knowledge of the solute and solvent densities by means of equation:

$$\rho_{soln} = \frac{L+S}{\frac{L}{\rho_L}+\frac{S}{\rho_S}} \qquad 2.6$$

where L and S are the masses of the solvent (liquid) and solute (solid), respectively, and ρ_L *and* ρ_S are the densities of the respective components

2.1.7 Conductivity

The thermal conductivity, k, of a substance is defined as the rate of heat transfer by conduction across a unit area through a layer of unit thickness under the influence of a unit temperature difference, the direction of the heat transmission being normal to the reference area. Fourier's equation for steady conduction may be written as $\frac{\partial q}{\partial t} = -kA\frac{\partial \theta}{\partial x}$ where $q,\ t,\ A,\ \theta$ *and* x are units of heat, time, area, temperature and length (thickness), respectively.

The thermal conductivity of an aqueous solution of a salt is generally slightly lower than that of pure water at the same temperature.

2.1.8 Heat Capacity

The amount of heat energy associated with a given temperature change in a given system is a function of the chemical and physical states of the system. The measure of this heat energy can be quantified in terms of the quantity known as the heat capacity that may be expressed on a mass or molar basis. The former designates the specific heat capacity ($Jkg^{-1} K^{-1}$) and the later the molar heat capacity ($J\ mol^{-1}K^{-1}$)

For dilute aqueous solutions of inorganic salts, ignoring the heat capacity contribution of the dissolved substance, a rough estimate of the specific heat capacity is obtained from

$$C = 1 - Y \qquad 2.7$$

where

Y - Is expressed in mass of the solute to the mass of the water

C- Is expressed in $Cal.g^{-1}k^{-1}$

This estimation cannot be applied to aqueous solution of non-electrolytes

Another rough estimation method for specific heat capacity of aqueous solution is based on the empirical relationship:

$$C = \rho^{-1} \qquad 2.8$$

where

ρ *– Density of the solution*

2.2 Evaporation Principles

2.2.1 Definition of Evaporation

Interestingly evaporation is often not defined in pure chemical and physics texts .This is because evaporation is a non-technical interpretation of more fundamental physical processes. Evaporation or condensation occurs when a liquid is not in equilibrium with its vapor or gas phase. Therefore, evaporation can be defined as the physical process in which a liquid is changed into a gas by molecular transfer. Condensation is the reverse process.

Evaporation is often misleadingly defined as '*the transfer of water from the liquid state*", though this definition is adequate for most purposes. It is, however, misleading because water is not the only substance evaporated in ambient temperatures. All liquids evaporate, including glass, mercury and ethanol. It is also misleading because it does not impart any understanding of the process of evaporation.

2.2.2 Vapor Pressure

Evaporation can be better understood by understanding the notion of vapor pressure of a liquid. Molecules in a liquid are in constant movement. The average rate of movement depends on the kinetic energy of the system, which is indirectly measured as temperature. Molecules with high kinetic energy will often move away from the attraction of the other molecules into the ambient gas or air, as it mostly is. These molecules may remain as a gas or vapor or return to the liquid phase. All liquids emit these molecules as vapor, causing the liquid to have a vapor pressure over the surface of the liquid. The liquid will continue to have a net movement of molecules to the ambient gas until equilibrium is reached. The vapor pressure at equilibrium (vapor pressure) is dependant on the kinetic energy (i.e. temperature) and the property of the liquid. Glass, for instance, has a very low vapor pressure at ambient temperature. As the temperature of the liquid increases, then the equilibrium vapor pressure of the liquid increases. As the temperature of the ambient gas (air) increases, the partial pressure of liquid in the gas (relative humidity) decreases for a constant mass of vapor.

The principles of evaporation process are rather simple. Evaporation is the process of equilibrating the vapor pressure of the liquid to the equilibrium partial vapor pressure of the liquid in the ambient gas or air. Increasing evaporation means doing one of the following,

- Increasing the equilibrium vapor pressure of the liquid,
- Decreasing the equilibrium partial pressure of the liquid in the ambient gas or air, or
- Increasing the rate of transfer from the liquid to the gas state.

For the purposes of this report, the following discussion will focus on the evaporation of water from an aquatic solution or brine in ambient air. This will allow for a more specific discussion.

2.2.3 Equilibrium Vapor Pressure of Brines

The equilibrium vapor pressure of pure water is well known and defined in many texts. The difference in vapor pressure between water at 30 degrees (31.824 mm Hg) and 40 degrees (55.324 mmHg) Celsius is an increase of 73%. Temperature increases the amount of vapor suspended over the body of liquid (water) at equilibrium.

The temperature of a brine or water in a field situation is dependant on the incident solar radiation as the (only) source of energy input. To maximize the temperature of an evaporating solution, it is important to expose the water/brine to the greatest solar radiation and retain as much of the incident radiation as possible, minimizing heat loss by reflection and absorption through the ground, with the only energy loss being through evaporation.

The area of the evaporating brine exposed to incident radiation is therefore critical. This is normally interpreted as surface area of the evaporation pond but may not always. As the area covered by brine increases, the greater will be the potential incident radiation.

Loss of incident radiation through reflection is an important consideration when the water being evaporated is brine. This is because the salt precipitated from brine increases the reflection and therefore heat loss. This is countered commercially by the use of dyes to increase solar absorption or by increasing the depth of the brine being evaporated. Increasing the depth of brine reduces the chance of the solar energy being reflected before the energy has been absorbed. The optical density of brines increases with salinity. Efficient light absorption and the conversion of light to heat are higher for a smaller depth of brine than pure water. In practice, if the depth of brine is greater than 50 cm then changing the absorption and reflective characteristics of the brine is not considered commercially viable for salt production.

In theory, it is possible to lose energy through diffusion of heat to the atmosphere. In practice this is not a major heat loss compared to the loss of heat through water vapor or evaporation.

Dissolved salts decrease the vapor pressure of an aqueous solution. Brines have a lower equilibrium vapor pressure at the same temperature as pure water. To minimize the effect of the equilibrium vapor pressure, decreasing with salinity in commercial solar evaporation plants, brines are separated into an evaporating sequence over a number of ponds, from lowest salinity to highest salinity, with the highest salinity ponds windward of the lower salinity ponds. The mean vapor pressure of the brines in ponds in a salinity sequence is higher than the vapor pressure of sole pond with homogenous brine.

2.2.4 Partial Pressure of Water in Air

The equilibrium partial pressure of water in air is mostly dependant on the temperature of the air and is not easily manipulated. Another factor that affects the equilibrium partial pressure of water in the air is the air pressure itself. A drop in air pressure will often result in precipitation of water (rain). There are local changes in the partial pressure of water in air. A cold area out of the sun is likely to have a higher relative water partial pressure but, these situations are indicative of disequilibria states.

2.2.5 Rate of Transfer

The rate of water transfer from a water body to the air is directly dependent on the surface area, and the relative difference between the equilibrium vapor pressure of the water to the existing partial pressure of water in the air.

Water bodies can effectively form an insulating cover of water vapor over the surface. The air immediately adjacent to the water body can be at equilibrium pressure and gradually becoming less at a distance from the surface. The initial laminar layer (only millimeters thick) adjacent to the water body is controlled by molecular diffusion. At a greater height above the water, the water vapor is mixed via a process of eddy diffusion. The larger the water body, the larger the influence or resistance to evaporation due to water vapor in the upper layers. This layer has been found to be only several meters thick in open lakes.

2.2.6 Measurement of Evaporation

Evaporation is not a simple phenomenon to measure, as it is a cumulation of a number of ***chemicals***, ***physical*** and ***meteorological*** variables. It should not be surprising that the measurement of evaporation has been approached from a number of different levels and using different technologies.

Pan evaporation provides the basis for the mass balance calculation of evaporation. By itself, it is a pointless expression of lake evaporation either freshwater or saline, but as a variable in calculating local potential evaporation, it is very useful.

A common equation for estimating evaporation from a large saline water body is as follows:

$$\text{Evaporation} = \text{Lake Factor} * \text{Salinity Factor} * (\text{Pan Evaporation} - \text{Rainfall}) \qquad 2.9$$

Lake Factor is normally assumed to be 70% or 0.7 but this may be less as in the example of a pit where it would drop to at least to 0.65. The salinity factor is normally assumed to be 0.7 for saturated brines.

2.3 Parameters Determining Solar Evaporation

2.3.1 Meteorological Variables

1. Solar radiation
2. Air temperature
3. Air humidity
4. Wind speed

The meteorological factors determining evaporation are weather parameters which provide energy for vaporization and remove water vapor from the evaporating surface. The principal weather parameters to consider are presented below.

1. Solar Radiation

The evaporation process is determined by the amount of energy available to vaporize water. Solar radiation is the largest energy source and is able to change large quantities of liquid water into water vapor. The potential amount of radiation that can reach the evaporating surface is determined by its location and time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds, which reflect and absorb major parts of the radiation. When assessing the effect of solar radiation on evaporation, not all-available energy is used to vaporize water. Part of the solar energy is used to heat up the atmosphere and the soil profile.

2. Air Temperature

The solar radiation absorbed by the atmosphere and the heat emitted by the earth increase the air temperature. The sensible heat of the surrounding air transfers energy to the surrounding and exerts as such a controlling influence on the rate of evaporation. In sunny, warm weather the loss of water by evaporation is greater than in cloudy and cool weather.

3. Air Humidity

While the energy supply from the sun and surrounding air is the main driving force for the vaporization of water, the difference between the water vapor pressure at the evaporating surface and the surrounding air is the determining factor for the vapor removal. High humidity of the air will reduce the evaporation demand. In such an environment, the air is already close to saturation, so that less additional water can be stored and hence the evaporation rate is lower than in arid regions.

4. Wind Speed

The process of vapor removal depends largely on wind and air turbulence that transfers large quantities of air over the evaporating surface. When vaporizing water, the air above the evaporating surface becomes gradually saturated with water vapor. If this air is not continuously replaced with drier air, the driving force for water vapor removal and the evaporation rate decreases.

The evaporation demand is high in hot dry weather due to the dryness of the air and the amount of energy available as direct solar radiation and latent heat. Under these circumstances, much water vapor can be stored in the air while wind may promote the transport of water allowing more water vapor to be taken up. On the other hand, under humid weather conditions, the high humidity of the air and the presence of clouds cause the evaporation rate to be lower. The drier the atmosphere the larger the effect on evaporation and the greater the slope of the curve will be. For humid conditions, the wind can only replace saturated air with slightly less saturated air and remove heat energy. Consequently, the wind speed affects the evaporation rate to a far lesser extent than under arid conditions where small variations in wind speed may result in larger variations in the evaporation rate.

2.3.2 Atmospheric Parameters

1. Atmospheric pressure (P)
2. Latent heat of vaporization (λ)
3. Psychometric constant (γ)

1. 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 as expressed in the psychometric constant. The 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:

$$P = 101.325\left(\frac{293 - 0.006 * z}{293}\right)^{5.28} \qquad 2.10$$

where

P- Atmospheric pressure [kPa],

z - Elevation above sea level [m],

2. Latent Heat of Vaporization (λ)

The latent heat of vaporization, λ, expresses the energy required to change a unit mass of water from liquid to water vapor in a constant pressure and constant temperature process. The value of the latent heat varies as a function of temperature. At a high temperature, less energy will be required than at lower temperatures. As λ varies slightly over normal temperature ranges it is better to use the following relation

$$\lambda = 2.501 - 0.002361T \qquad 2.11$$

3. Psychometric Constant (γ)

The psychometric constant, γ is given by:

$$\gamma = \frac{Cp\ P}{\varepsilon\lambda} = 0.665\times10^{-3}\,P \qquad 2.12$$

where

γ - Psychometric constant [kPa °C^{-1}],

P- Atmospheric pressure [kPa],

λ - Latent heat of vaporization [MJ kg^{-1}],

c_p- Specific heat at constant pressure, 1.013 *10^{-3} [MJ kg^{-1} °C^{-1}],

ε - Ratio molecular weight of water vapor/dry air = 0.622.

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 value c_p = 1.013*10^{-3} MJ kg^{-1} °C^{-1} can be used. As an average atmospheric pressure is used for each location, the psychometric constant is kept constant for each location.

2.4 Determination of Air Humidity

The water content of the air can be expressed in several ways: vapor pressure, dew point temperature and relative humidity are common expressions to indicate air humidity.

2.4.1 Vapor Pressure

Water vapor is a gas and its pressure contributes to the total atmospheric pressure. The amount of water in the air is related directly to the partial pressure exerted by the water vapor in the air and is therefore a direct measure of the air water content.

When air is enclosed above an evaporating water surface, equilibrium is reached between the water molecules escaping and returning to the water reservoir. At that moment, the air is said to be saturated since it cannot store any extra water molecules. The corresponding pressure is called the saturation vapor pressure (e° (T)). The number of water molecules that can be stored in the air depends on the temperature (T). The higher the air temperature, the higher the storage capacity and the higher its saturation vapor pressure.

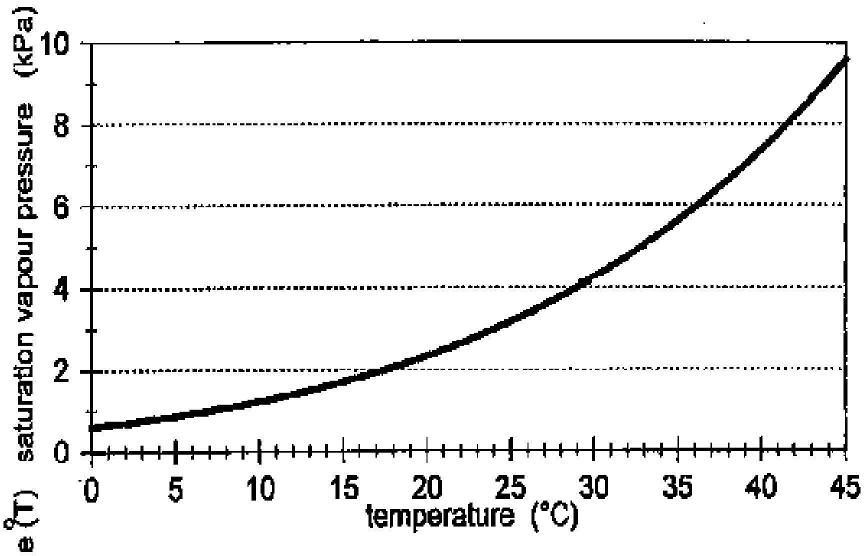


Fig 2.3 saturation vapor pressure shown as a function of temperature: e^o (T) Curve

As can be seen from Figure 2.3, the slope of the curve changes exponentially with temperature. At low temperatures, the slope is small and varies only slightly as the temperature rises. At high temperatures, the slope is large and small changes in T result in large changes in slope. The slope of the saturation vapor pressure curve, Δ is an important parameter in describing vaporization and is required in the equations for calculating evaporation rate from climatic data.

The actual vapor pressure (e_a) is the vapor pressure exerted by the water in the air. When the air is not saturated, the actual vapor pressure will be lower than the saturation vapor pressure. The difference between the saturation and actual vapor pressure is called *the vapor pressure deficit* or *saturation deficit* and is an accurate indicator of the actual evaporative capacity of the air.

2.4.2 Dew Point Temperature

The dew point temperature is the temperature to which the air needs to be cooled to make the air saturated. The actual vapor pressure of the air is the saturation vapor pressure at the dew point temperature. The drier the air, the larger the difference between the air temperature and dew point temperature will be.

2.4.3 Determination of Mean Saturation Vapor Pressure

As saturation vapor pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by:

$$e^0(T) = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right] \qquad 2.13$$

where

$e^0(T)$ - Saturation vapor pressure at air temperature T [kPa]

T - Air temperature

Due to the non-linearity of the above equation, the mean saturation vapor pressure for a day, week, decade or month should be computed as the mean between the saturation vapor pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e^0(T_{\max}) + e^0(T_{\min})}{2} \qquad 2.14$$

Using mean air temperature instead of daily minimum and maximum temperatures results in lower estimates for the mean saturation vapor pressure. The corresponding vapor pressure deficit (a parameter expressing the evaporating power of the atmosphere) will also be smaller and the result will be some underestimation of the evaporation rate. Therefore, the mean saturation vapor pressure should be calculated as the mean between the saturation vapor pressure at both the daily maximum and minimum air temperature.

2.4.4 Slope of Saturation Vapor Pressure Curve (Δ)

For the calculation of evaporation, the slope of the relationship between saturation vapor pressure and temperature, Δ, is required. The slope of the curve (Figure 2.1) at a given temperature is given by.

$$\Delta = \frac{4080\left[0.6108\left(\frac{17.27}{T+273.3}\right)\right]}{(T+273.3)^2} \qquad 2.15$$

where

Δ - Slope of saturation vapor pressure curve at air temperature T [kPa °C^{-1}],

T -Air temperature [°C],

2.4.5 Actual Vapor Pressure (e_a) Derived from Dew Point Temperature

As the dew point temperature is the temperature to which the air needs to be cooled to make the air saturated, the actual vapor pressure (e_a) is the saturation vapor pressure at the dew point temperature (T_{dew}) [°C], or:

$$e_\partial = e^o = 0.6108 * \exp\left[\frac{17.27 * T_{dew}}{T_{dew} + 237.3}\right] \qquad 2.16$$

Actual vapor pressure (e_a) derived from relative humidity data

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.

· For RH_{max} and RH_{min}:

$$e_a = \frac{e^o(T_{min})\frac{RH_{max}}{100} + e^o(T_{max})\frac{RH_{min}}{100}}{2} \qquad 2.17$$

where

e_a -Actual vapor pressure [kPa],

$e°(T_{min})$- Saturation vapor pressure at daily minimum temperature [kPa],

$e°(T_{max})$-Saturation vapor pressure at daily maximum temperature [kPa],

RH_{max} -Maximum relative humidity [%],

RH_{min} -Minimum relative humidity [%].

For periods of a week, ten days or a month, RH_{max} and RH_{min} are obtained by dividing the sum of the daily values by the number of days in that period.

2.4.6 Vapor Pressure Deficit (e_s - e_a)

The vapor pressure deficit is the difference between the saturation (e_s) and actual vapor pressure (e_a) for a given time period.

2.5 Determination of Radiation

2.5.1 Extraterrestrial Radiation (R_a)

The radiation striking a surface perpendicular to the sun's rays at the top of the earth's atmosphere, called the solar constant, is about $0.082 MJm^{-2}min^{-1}$. The local intensity of radiation is, however, determined by the angle between the direction of the sun's rays and the normal to the surface of the atmosphere. This angle will change during the day and will be different at different latitudes and in different seasons. The solar radiation received at the top of the earth's atmosphere on a horizontal surface is called the extraterrestrial (solar) radiation, R_a.

If the sun is directly overhead, the angle of incidence is zero and the extraterrestrial radiation is $0.0820 MJm^{-2}min^{-1}$. As seasons change, the position of the sun, the length of the day and, hence, R_a change as well. Extraterrestrial radiation is thus a function of latitude, date and time of day.

2.5.2 Solar or Shortwave Radiation (R_s)

As the radiation penetrates the atmosphere, some of the radiation is scattered, reflected or absorbed by the atmospheric gases, clouds and dust. The amount of radiation reaching a horizontal plane is known as the solar radiation, R_s. Because the sun emits energy by means of electromagnetic waves characterized by short wavelengths, solar radiation is also referred to as shortwave radiation.

2.5.3 Relative Shortwave Radiation (R_s/R_{so})

The relative shortwave radiation is the ratio of the solar radiation (R_s) to the clear-sky solar radiation (R_{so}). R_s is the solar radiation that actually reaches the earth's surface in a given period, while R_{so} is the solar radiation that would reach the same surface during the same period but under cloudless conditions.

The relative short wave radiation is a way to express the cloudiness of the atmosphere; the cloudier the sky the smaller the ratio. The ratio varies between about 0.33 (dense cloud cover) and 1 (clear sky). In the absence of a direct measurement of R_n, the relative short wave radiation is used in the computation of the net long wave radiation.

2.5.4 Relative Sunshine Duration (n/N)

The relative sunshine duration is another ratio that expresses the cloudiness of the atmosphere. It is the ratio of the actual duration of sunshine, n, to the maximum possible duration of sunshine or daylight hours N. In the absence of any clouds, the actual duration of sunshine is equal to the daylight hours ($n = N$) and the ratio is one, while on cloudy days $n=0$ and consequently the ratio may be zero. In the absence of a direct measurement of R_s, the relative sunshine duration, n/N, is often used to derive solar radiation from extraterrestrial radiation.

As with extraterrestrial radiation, the day length N depends on the position of the sun and is hence a function of latitude and date.

2.5.5 Albedo (a) and Net Solar Radiation (R_{ns})

A considerable amount of solar radiation reaching the earth's surface is reflected. The fraction, α, of the solar radiation reflected by the surface is known as the albedo. The albedo is highly variable for different surfaces and for the angle of incidence or slope of the ground surface. It may be as large as 0.95 for freshly fallen snow and as small as 0.05 for a wet bare soil.

The net solar radiation, R_{ns}, is the fraction of the solar radiation R_s that is not reflected from the surface. Its value is (1- α) Rs.

2.5.6 Net Long-Wave Radiation (R_{nl})

The solar radiation absorbed by the earth is converted to heat energy. By several processes, including emission of radiation, the earth loses this energy. The earth, which is at a much lower temperature than the sun, emits radiative energy with wavelengths longer than those from the sun. Therefore, the terrestrial radiation is referred to as long-wave radiation. The emitted long-wave radiation ($R_{l, up}$) is absorbed by the atmosphere or is lost into space. The long-wave radiation received by the atmosphere ($R_{l, down}$) increases its temperature and, as a consequence, the atmosphere radiates energy of its own. Part of the radiation finds it way back to the earth's surface. Consequently, the earth's surface both emits and receives long-wave radiation. The difference between outgoing and incoming long-wave radiation is called the net long-wave radiation, R_{nl}. As the outgoing long-wave radiation is almost always greater than the incoming long-wave radiation, R_{nl} represents an energy loss.

2.5.7 Net Radiation (R_n)

The net radiation, R_n, is the difference between incoming and outgoing radiation of both short and long wavelengths. It is the balance between the energy absorbed, reflected and emitted by the earth's surface or the difference between the incoming net shortwave (R_{ns}) and the net outgoing long-wave (R_{nl}) radiation. R_n is normally positive during the daytime and negative during the night time. The total daily value for R_n is usually positive over a period of 24 hours, except in extreme conditions at high latitudes.

2.5.8 Extraterrestrial Radiation for Daily Periods (R_a)

The extraterrestrial radiation, R_a, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \quad 2.18$$

where

$R_a - Exteraterristerial radiation \left[MJm^{-2}day^{-1}\right]$

$Gsc - Solar\ cons\tan t = 0.0820\left[MJm^{-2}day^{-1}\right]$

$d_r - Inverse\ relative\ dis\tan ce\ earth - sun\ [-]$

$\omega_s - Sunset\ hour\ angle\ [rad]$

$\varphi - Latitude\ [rad]$

$d_r - Solar\ declication[rad]$

The inverse relative distance Earth-Sun, d_r and the solar declination, δ are given by:

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365} J\right) \quad 2.19$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365} J - 1.39\right) \quad 2.20$$

Where

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

The sunset hour angle, ω, is given by:

$$\omega_s = \arccos\ [-\tan(\delta)\tan(\varphi)] \quad 2.21$$

2.5.9 Daylight Hours (N)

The daylight hours, N, are given by:

$$N = \frac{24}{\pi} \omega s \qquad 2.22$$

2.6 Brine Depth

Considerable studies have been conducted to analyze the effect of brine depth up on the net evaporation. The shallower the brine depth the greater the evaporation rate will be. The reason for this is that with shallower ponds, the brine heats up quicker and hotter, and thus can have higher vapor pressure for a long period of time. The shallower brine also gets colder in the evening, and deeper ponds have a more stable, uniform temperature. More concentrated brines (with their lower vapor pressure) respond best to shallower operation. However, in all cases the wind can have an overriding influence. Vigorously, uniform winds will completely nullify the effect of brine depth, and higher winds during the non-sunshine hours can even make the deeper ponds show a higher evaporation rate.

Figure 2.4 (a) represents brine temperature (^{O}C) distribution on three different depths: 20 cm 50 cm and 70 cm over the day. In the graph, it is possible to see three different regions. To the left of the graph the brine with higher depth has higher temperature. In the middle, the condition will be reversed and on the right side, it goes to the first condition. Brines with higher depth have energy storage capacity. Fig 2.4 (b) indicates the wind speed (km per hour) over the day. Fig 2.4 (c) shows air temperature ^{O}C and relative humidity (%) over the day a

b

c

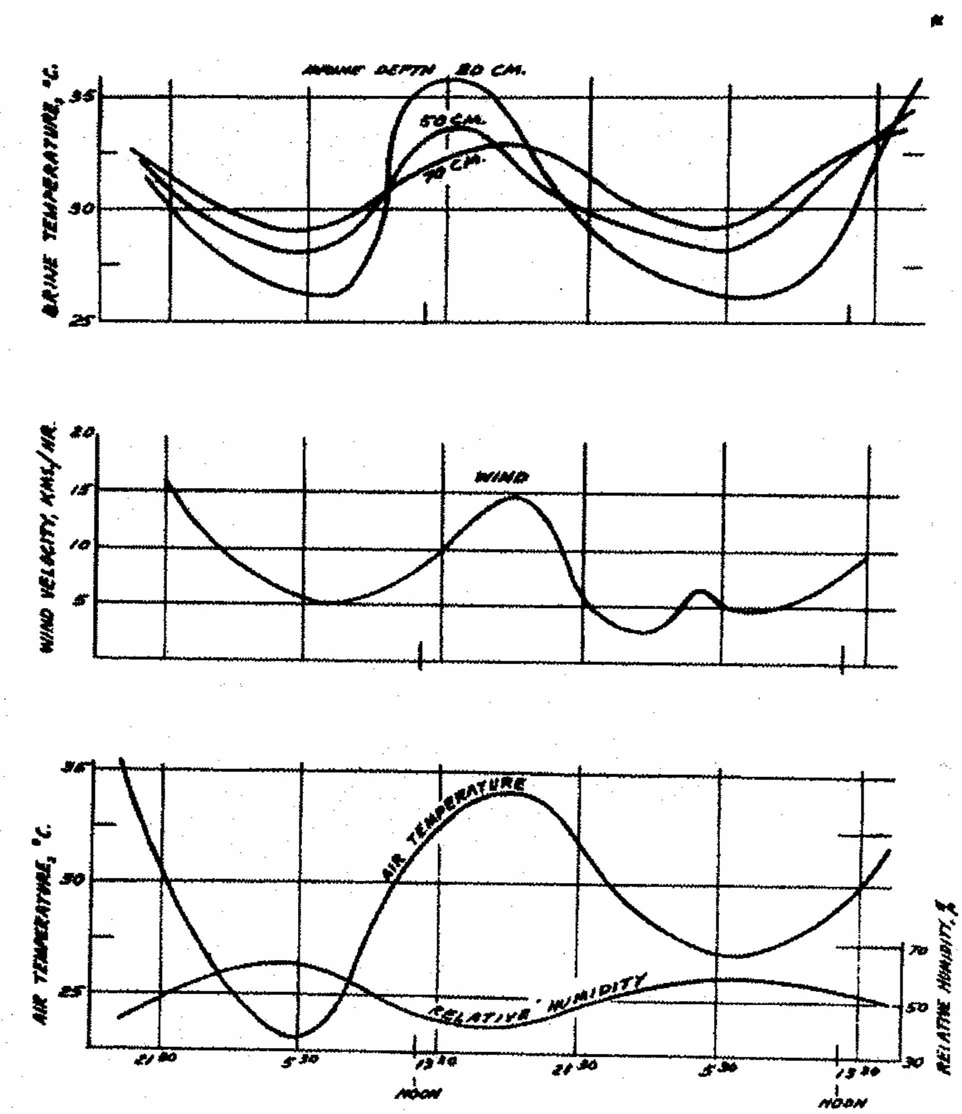


Fig 2.4 Typical temperature curve for different depth

2.7 Penman Equation to Determine Evaporation Rate

To determine evaporation rate using Penman's equation, the following parameters should be known:

- Location of the field (latitude in degree)
- Elevation of the field (mean see level)
- Day of the year
- Mean air temperature
- A measure of average humidity for this day (relative humidity or dew point temperature or pressure
- Daily solar radiation
- Average wind speed for this day

$$\lambda E_o = \frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma} f(v)(e_s - e_a) \qquad 2.23$$

$$f(v) = 6.43(1.0 + 0.53v) \qquad 2.24$$

$R_n - Net\ radiation\ [MJm^{-2}day^{-1}]$,

$G - Soil\ flux\ density\ MJm^{-2}day^{-2}\ which\ is\ assumed\ to\ be\ negligble = 0$

$T - Temperature\ at\ 2\ m\ height\ [{}^{O}C]$

$v - Wind\ speed\ at\ 2m\ height\ [m/s]$

$e_s - Saturation\ vapor\ pressure\ [kPa]$

$e_a - Actual\ vapor\ pressure\ [kPa]$

$(e_s - e_a) - Saturation\ vapor\ pressure\ deficient\ [kPa]$

$\Delta - Slope\ of\ vapor\ pressure\ curve\ [kPa\ {}^{O}C^{-1}]$

$\gamma - Psychometric\ constant\ [kPa\ {}^{O}C^{-1}]$

2.8 Heat Transfer in Ponds

Solar energy is identified as the main heating mechanism for ponds. The main cooling mechanism is evaporation. Thermal radiation can also account for a significant amount of cooling during night hours. Convective heating or cooling to the atmosphere is less significant. Conductive heat transfer to the ground is generally a relatively insignificant process, except in cases where the water surface is frozen. For the case of this thesis work there is no conduction loss to the ground since it is well insulated.

Governing Equation

The governing equation of the models as over all energy balance on the pond using the lumped capacitance (or lumped parameter model) approach

$$\dot{q}_{in} - \dot{q}_{out} = d\rho\ C_P \frac{dT}{dt} \qquad 2.25$$

Where

$\dot{q}_{in}$ – Heat trnsfer to the pond $[W/m^2]$

$\dot{q}_{out}$ – Heat trnsfer from the pond $[W/m^2]$

d – Depth of the pond $[m]$

ρ – Density of the pond water $[kg/m^3]$

C_P – Specific heat of the pond water $[kJ\ kg^{-1}K^{-1}]$

$\frac{dT}{dt}$ – Rate of temprature of the pond water $[K/s]$

This approach assumes that temperature gradient within the water body can be neglected.

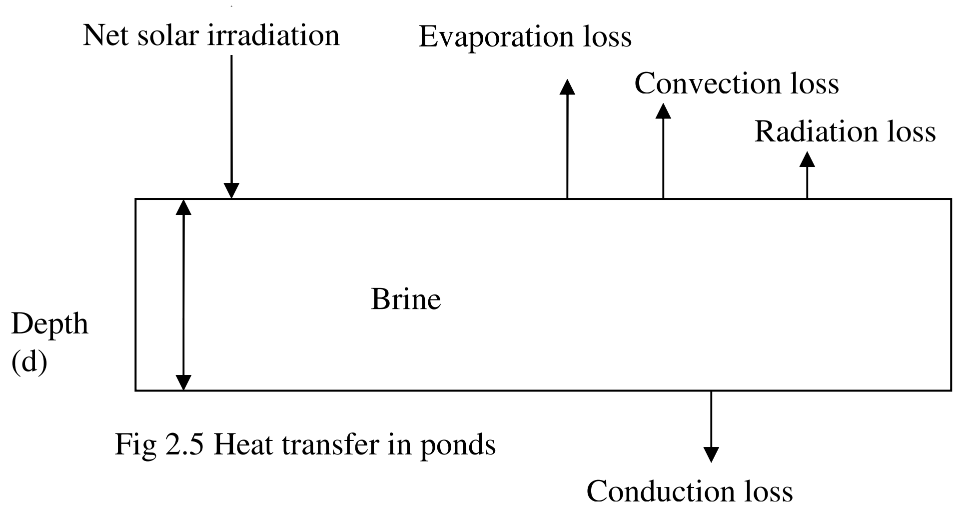


Fig 2.5 Heat transfer in ponds

Considering the heat transfer mechanisms shown in figure 2.5, equation 2.25 can be expressed to describe the rate of change in average pond temperature

$$\frac{dT}{dt} = \frac{\left(\dot{q}_{solar} + \dot{q}_{thermal} + \dot{q}_{convective} + \dot{q}_{conductive} + \dot{q}_{evaporation}\right)}{d\rho\ C_P} \qquad 2.26$$

where

$\dot{q}_{solar}$ - *Solar radiant heat gain to the pond*

$\dot{q}_{thermal}$ - *Thermal radiant heat transfer at the pond*

$\dot{q}_{convective}$ - *Convective heat transfer at the pond surface*

$\dot{q}_{conduction}$ - *Heat transfer to/from the pond in contact to the pond*

$\dot{q}_{evaporation}$ - *Heat/mass transfer due to evaporation at the pond surface*

Each of the heat transfer terms used in the above equation is defined briefly below

1. Solar Radiant Heat Gain

Solar radiant heat gain (q_{solar}) is the net solar radiation adsorbed by the pond. It is assumed that all solar radiation incident on the pond surface become heat gain except for the portion reflected at the surface

$$\dot{q}_{solar} = I(1-\rho)A_{pond} \qquad 2.27$$

Where

I - Solar radiant flux incident in the pond surface

2. Thermal Radiant Heat Gain

This heat transfer mechanism accounts for heat transfer at the pond surface due to thermal or long wave radiation. This model uses a radiation coefficient (h_r) defined as

$$\dot{q}_{thermal} = \varepsilon\ \sigma(\ T_{pond}^4 - T_{sky}^4\ ) \qquad 2.28$$

Where

($q_{thermal}$) - The thermal radiant heat transfer

ε - The emissive coefficient of the pond water [-]

σ - The stefan-Botzman constant [$Wm^{-2}\ K^{-1}$]

T_{pond} - Pond temperature in the absolute units [K]

T_{sky} - The sky temperature in absolute units [K]

3. Convective losses

Convective losses depend directly on the temperature difference between the air and the brine, as well as on the air flow velocity, by ways of the adopted convection coefficient

$$q_{convective} = h_c\left(T_{air} - T_{brine}\right) \qquad 2.30$$

$$h_c = 2.8 + 3.0v \qquad 2.31$$

where

$v - Air\ velocity\ \left[{}^{m}\!/\!{}_{s}\right]$

4. Evaporation losses

The calculation of the evaporation losses is given by the following expression

$$q_{evaporation} = H_{fg}\, mass_w$$

$H_{fg} - Latent\ heat\ of\ vaporization$

$mass_w - Mass\ of\ water\ evaporated\ [mm]$

5. Mass of water evaporated

The mass of water evaporated can be calculated from the evaporation rate

$$mass_w = \rho\ A\ ETo * 1000 \qquad 2.32$$

where

$\rho - Density\ of\ pond\ water\ [kg/m^3]$

$A - Area\ of\ the\ pond\ [m^2]$

$ETo - Evaporated\ water\ [mm]$

CHAPTER THREE
METHODOLOGY

3.1 Physical Model Development

One of the methodologies is to develop the physical model. A physical model is one that resembles an actual system and is generally used to obtain experimental results on the behavior of the system. It is a scaled down version of the actual system, the solar evaporation pond, for study of the basic characteristics of the system. The models are fabricated in the workshop using sheet metal. It is coated with anti-rust to protect rusting. And it is also black coated in order to absorb the solar irradiation. The model is double for three different depths: 25, 20 and 10 cm. Six peaces were produced with double depth size to have two different concentrations (density gradient).

The six different evaporation pond models the following characteristics the base area 25cmx 45 cm both sides are inclined at 15^{O} angle up the desired depth. This is in order to:

1. Increase the surface area for solar radiation. Further increase of inclination angle will increase the convective heat transfer loss
2. At the bottom the concave shape will have greater density gradient which initiates crystallization

The six different evaporation model pans were given the following codes to differentiate one from the other. The first three pans hold dilute brines and have the following codes:

Dil-25 ⟶ Evaporation model pan having dilute brine at 25 cm

Dil-20 ⟶ Evaporation model pan having dilute brine at 20 cm

Dil-10 ⟶ Evaporation model pan having dilute brine at 10 cm

The rest three which will hold the concentrated brine have the following codes:

Con-25 ⟶ Evaporation model pan having concentrate brine at 25 cm

Con-20 ⟶ Evaporation model pan having concentrate brine at 20 cm

Con-10 ⟶ Evaporation model pan having concentrate brine at 10 cm

3.2 Data Collection

The following data were collected over 16 hours per day starting at 8:00am.

1. Temperature distribution of the evaporation pan models pre hour
2. Evaporation depth per three hours

The desired data was collected in a produced format.

The dilute brine was taken from the lake brine discharge at the pre-concentration ponds. The concentrated brine was taken from Trona crystallization pond. The dilute and concentrated brines were analyzed and the results obtained are presented as follows:

Table 3.1 Dilute brine compositions

Composition	**Percentage by weight**
Na_2CO_3	2.00
$NaHCO_3$	1.03
NaCl	1.21
Specific gravity	1.034

Table 3.2 Concentrated brine compositions

Composition	Percentage by weight
Na_2CO_3	6.98
$NaHCO_3$	4.29
NaCl	1.47
Specific gravity	1.11

3.3 Instruments Used for Measurement

1. **Thermometer** for temperature measurement
2. **Meter stick** for depth measurement

3.4 Laboratory Analysis

1. Chemical analysis
2. Specific gravity measurement for crystallized product.

3.5 Format Developed to Record the Data

Daily Follow up Format of Model Evaporation Pans

1. Dilute Brine

Date --------------

Instantaneous Brine Temperature with Respect to Time

Table 3.3 Format developed to record dilute brine temperature

Hour / Temp.(^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp.															
Dil-10															
Dil-20															
Dil-25															

Instantaneous Brine Depth with respect to time

Table 3.4 Format developed to record dilute brine depth

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Dil-10						
Dil-20						
Dil-25						

Daily Follow up Format for Model Evaporation Pans

2. Concentrated Brine

Date ---------------

Instantaneous Brine Temperature with respect to time

Table 3.5 Format developed to record concentrated brine temperature

Hour / Temp.(^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp.															
Con-10															
Con-20															
Con-25															

Instantaneous Brine Depth with Respect to Time

Table 3.6 Format developed to record concentrated brine depth

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Con-10						
Con-20						
Con-25						

3.6 Collected Data

Daily Follow up Format of Model Evaporation Pans

1. Dilute Brine

Date 30-04-2006

Instantaneous Brine Temperature with Respect to Time

Table 3.7 First day brine temperature for dilute brine

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp								*32*		*19*	*21.5*				
Dil-10								*37*		*29*	*28*				
Dil-20								*35*		*31*	*30*				
Dil-25								*35.5*		*31*	*30*				

Instantaneous Brine Depth with Respect to Time

Table 3.8 First day brine depth for dilute brine

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*9.5*		*9.0*	*9.0*		
Dil-20	*19.5*		*19.0*	*19.0*		
Dil-25	*24.5*		*24.0*	*24.0*		

Daily Follow up Format of Model Evaporation Pans

2. *Concentrated Brine*

Date 30-04-2006

Instantaneous Brine Temperature with Respect to Time

Table 3.9 First day brine temperature for concentrated brine

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp								32		19	21.5				
Con-10								37		29	28				
Con-20								35.5		32	31				
Con-25								34		31.5	31				

Insta
ntan

eous Brine Depth with Respect to Time

Table 3.10 First day brine depth for concentrated brine

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Con-10	*9.5*		*9.0*	*9.0*		
Con-20	*19.5*		*19.0*	*19.0*		
Con-25	*24.5*		*24.3*	*24.0*		

Other data's are in Annex A-D

3.7 Completion Date of Evaporation Pans

Table 3.7 completion date of evaporation pans

No	*Given code*	*Started date*	*Completion date*	*Completion hour*	*No of days*
1	Dil-10	30-04-2006	12-05-2006	15:00	13 days
2	Dil-20	30-04-2006	23-05-2006	18:00	24 days
3	Dil-25	30-04-2006	30-05-2006	18:00	31 days
4	Con-10	30-04-2006	11-05-2006	16:00	12 days
5	Con-20	30-04-2006	19-05-2006	16:00	20 days
6	Con-25	30-04-2006	25-05-2006	18:00	26 days

Remark: some interruptions of data is due to rain

CHAPTER FOUR

DATA ANALYSIS AND DISCUSSION

4.1 Analysis of Data

4.1.1 Evaporation Rate Calculated for Dilute Brine

Table 4.1 Evaporation rate of dilute brine

No	*Date*	*Dil-10 (mm)*	*Dil-20 (mm)*	*Dil-25 (mm)*	*Average Evaporation Rate(mm)*
1	30.04.06	5	5	5	5
2	01.05.06	10	9	9	9.33
3	02.05.06	6	5	4	5
4	03.05.06	6	6	6	6
5	04.05.06	6	7	7	6.67
6	05.05.06	7	4	7	6
7	06.05.06	3	6	3	4
8	07.05.06	6	7	6	6.33
9	08.05.06	7	9	7	7.67
10	09.05.06	9	7	9	8.33
11	10.05.06	7	8	7	7.33
12	11.05.06	7	9	8	8
13	12.05.06		7	10	8.5
14	13.05.06		8	6	7
15	14.05.06		7	9	8
16	15.05.06		6	7	6.5
17	16.05.06		7	7	7
18	17.05.06		6	5	5.5
19	18.05.06		11	11	11
20	19.05.06		9	10	9.5
21	20.05.06		7	7	7
22	21.05.06		7	7	7
23	22.05.06		4	5	4.5
24	23.05.06		8	10	9
25	24.05.06			6	6
26	25.05.06			8	8
27	26.05.06			6	6
28	27.05.06			5	5
29	28.05.06			4	4
30	29.05.06			5	5
31	30.05.06			4	4

4.1.2 Evaporation Rate Calculated for Concentrated Brine

Table 4.2 Evaporation rate of concentrated brine

No	***Date***	***Con-10 (mm)***	***Con-20 (mm)***	***Con-25 (mm)***	***Average Evaporation Rate(mm)***
1	30.04.06	5	5	5	5
2	01.05.06	10	9	9	9.33
3	02.05.06	7	6	6	6.33
4	03.05.06	5	5	4	4.67
5	04.05.06	7	8	8	7.67
6	05.05.06	5	6	5	7.67
7	06.05.06	3	3	3	3
8	07.05.06	6	5	5	5.33
9	08.05.06	6	8	9	7.67
10	09.05.06	7	9	9	8.33
11	10.05.06	5	6	5	5.33
12	11.05.06	5	7	5	5.67
13	12.05.06		8	9	8.5
14	13.05.06		7	8	7.5
15	14.05.06		4	4	4
16	15.05.06		5	7	6
17	16.05.06		5	4	4.5
18	17.05.06		6	7	6.5
19	18.05.06		6	8	7
20	19.05.06		4	6	5
21	20.05.06			7	7
22	21.05.06			6	6
23	22.05.06			5	5
24	23.05.06			3	3
25	24.05.06			6	6
26	25.05.06			5	5

4.1.3 Representation of Evaporation Rate

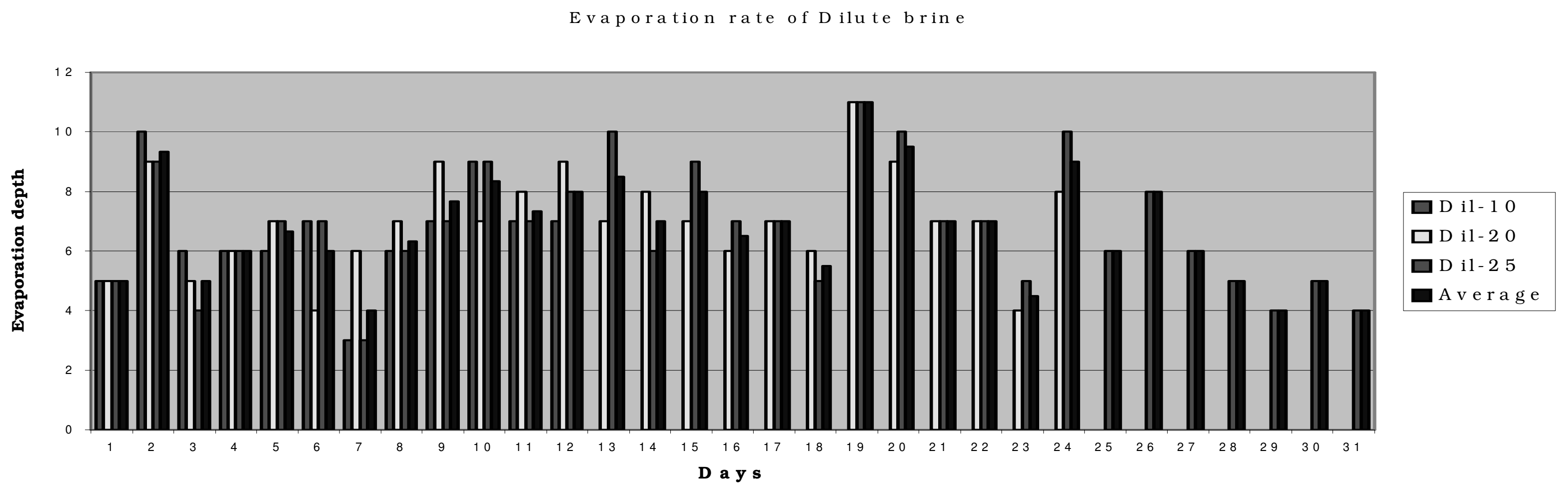


Fig 4.1 Evaporation rate of dilute brine

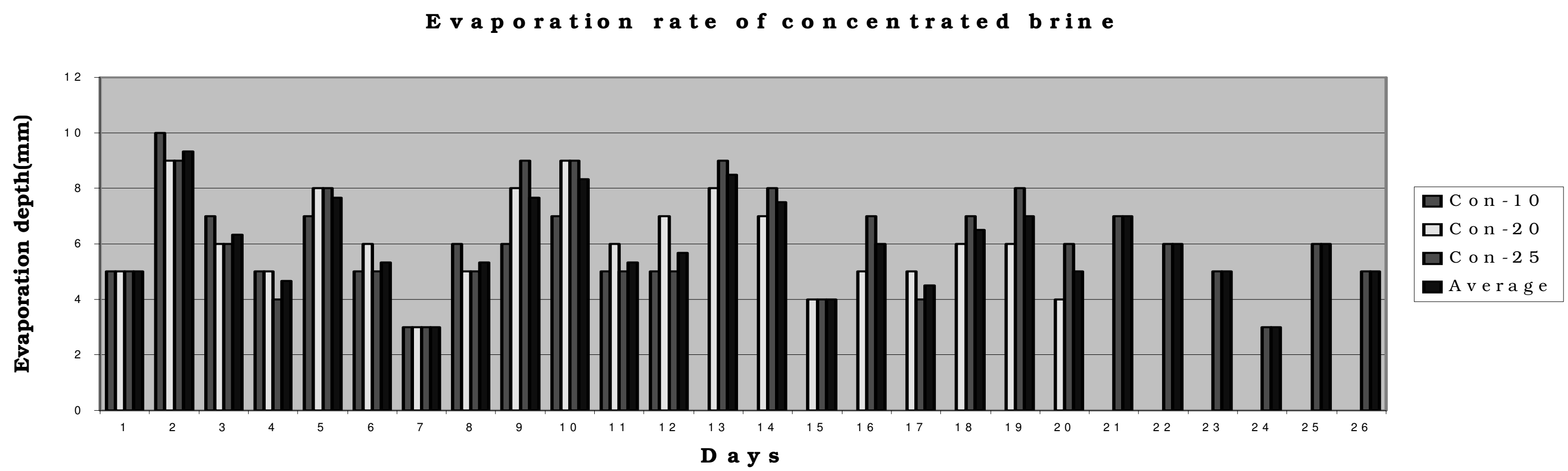


Fig 4.2 Evaporation rate of concentrated brine

4.1.3 Comparison of Average Evaporation Rate of Brine for the Two Concentrations

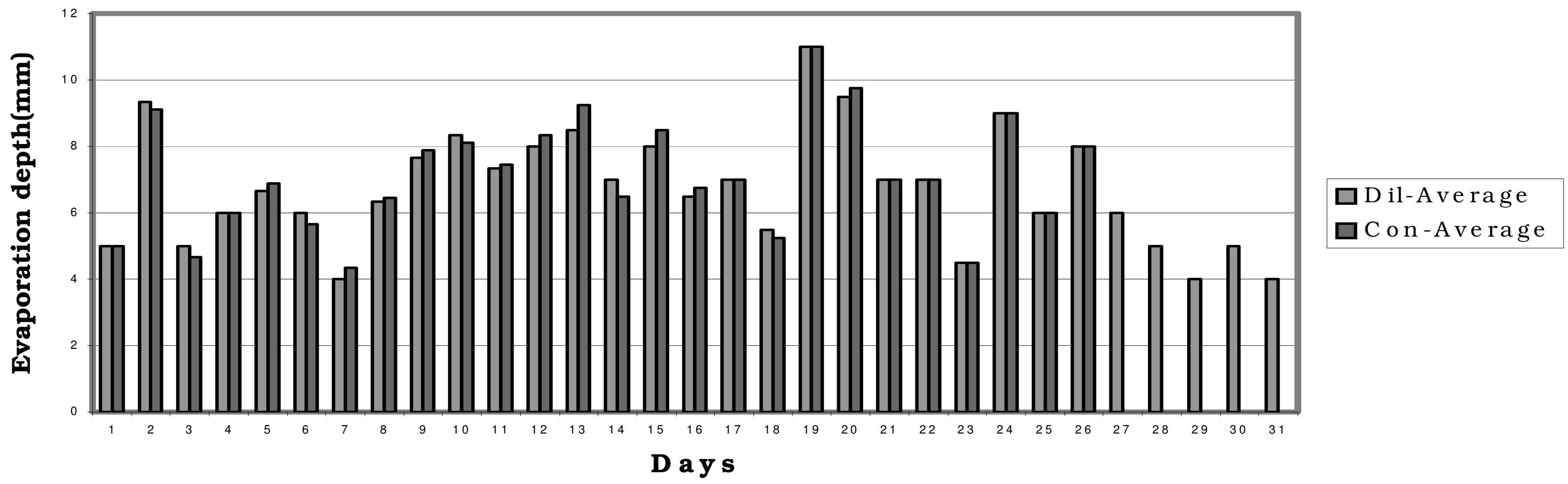
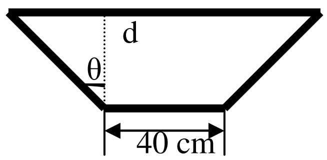


Fig 4.3 Average evaporation rate of dilute and concentrated brine

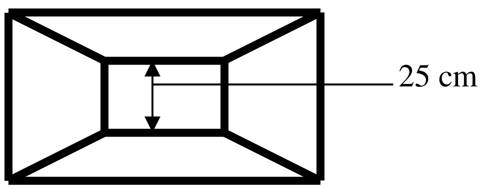
4.1.5 Mass Balance of the Evaporation Pans

1. Analysis of Dil-10

Density of the brine=1034Kg/m^3



$\theta=15^O$ depth=d=9.5 cm=0.095 m



The volume with this depth

$$V= (0.40+(d)\tan(15^O)) \times (0.25+(d)\tan(15^O)) \times (d)$$

$$= (0.40+(0.095)\tan(15^O)) \times (0.25+(0.095)\tan(15^O)) \times (d)$$

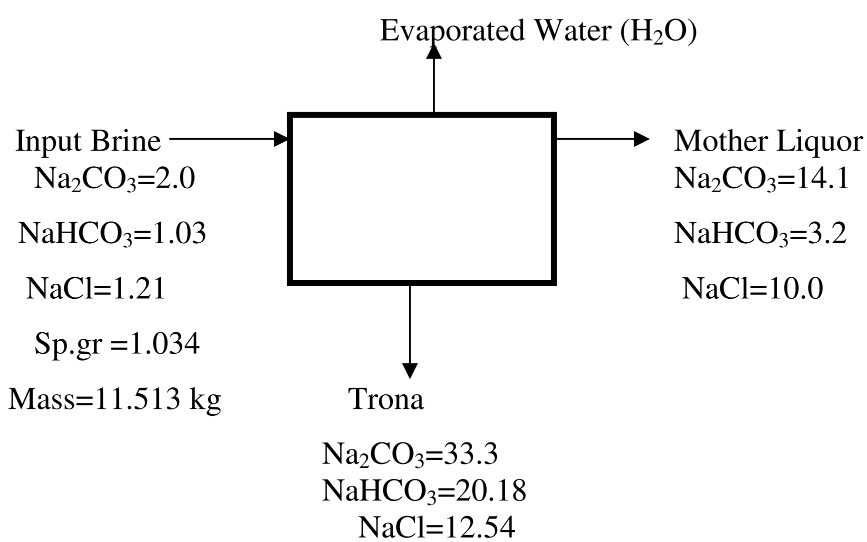
$$=0.0111334\ m^3$$

The mass of brine with this depth

Mass=Density * Volume

$=1034\ kg/m^3 * 0.0111334\ m^3$

=11.513 kg



Mass of **Mother Liquor** and **Trona** calculated using component balance

Mass of mother liquor = 819.1 gm

Mass of Trona = 457.8 gm

Mass of evaporated

Volume of the remaining product

Remaining depth=1.6 cm=0.016m

$V= (0.40+(d) \tan (15^O)) \times (0.25+(d) \tan (15^O)) \times (d)$

$= (0.40+(0.016) \tan (15^O)) \times (0.25+(0.016) \tan (15^O)) \times (0.016)$

$= 0.001644881 \ m^3$

$= 1.645$ Lit

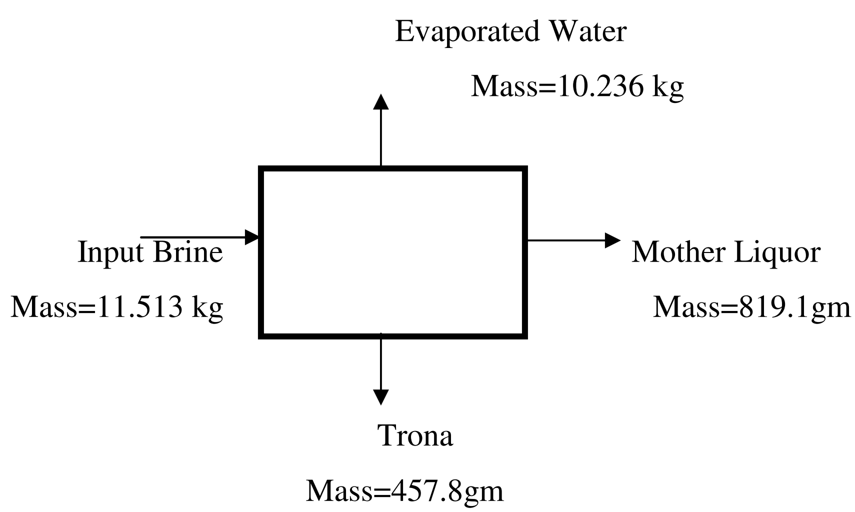
Volume of evaporated water = Total Volume - Remaining Volume

= 11.1334 Lit - 1.645 Lit

=10.4884 Lit

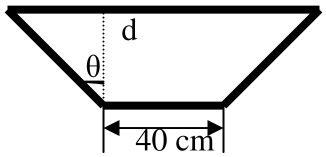
Mass of evaporated water =10.4884*1.0 kg/Lit

=10.4884 kg

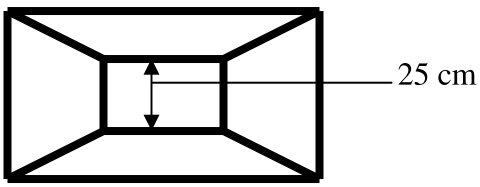


2. Analysis of Con-10

Density of the brine=1110 kg/m^3



$\theta=15^O$ depth=d=9.5 cm=0.095 m



The volume with this depth

$$V= (0.40+(d) \tan (15^O)) \times (0.25+(d) \tan (15^O)) \times (d)$$

$$= (0.40+(0.095) \tan (15^O)) \times (0.25+(0.095) \tan (15^O)) \times (d)$$

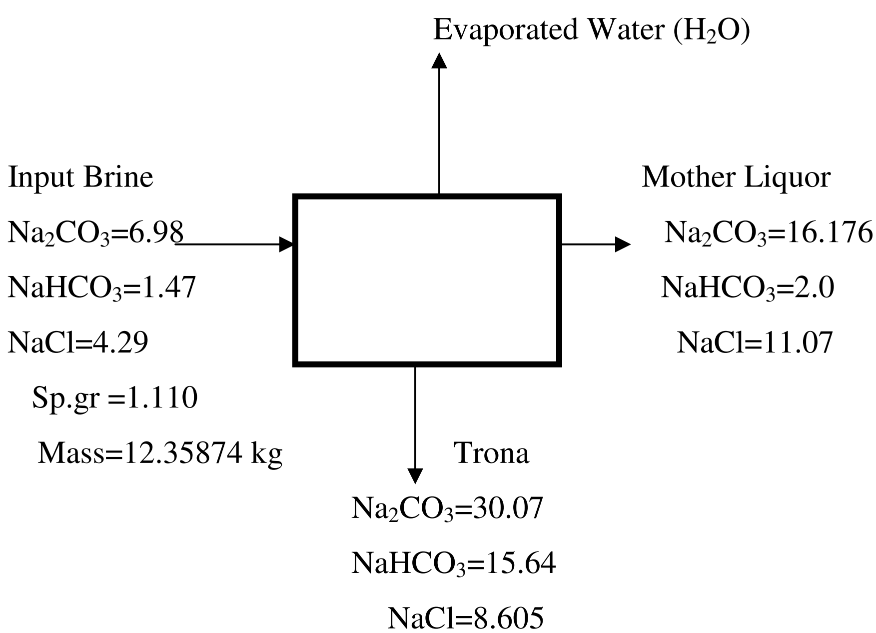
$$=0.0111334 \text{ m}^3$$

The mass of brine with this depth

Mass=Density * Volume

$=1110 \text{ kg/m}^3 * 0.0111334 \text{ m}^3$

$=12.35874$ kg



Mass of **Mother Liquor** and **Trona** calculated using component balance

Mass of mother liquor = 4.339 kg

Mass of Trona =0.5023 kg

Mass of evaporated

Volume of the remaining product

Remaining depth=3.1 cm=0.031 m

$V= (0.40+ (d) \tan (15^{O})) \times (0.25 + (d) \tan (15^{O})) \times (d)$

$= (0.40+(0.031) \tan (15^{O})) \times (0.25+(0.031) \tan (15^{O})) \times (0.031)$

$= 0.00327 \text{ m}^3$

= 3.27 Lit

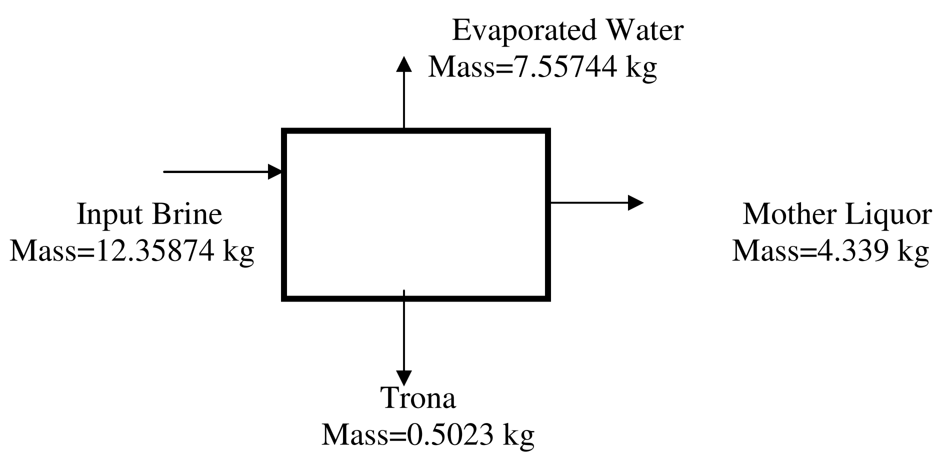
Volume of evaporated water = Total Volume - Remaining Volume

= 11.1334 Lit - 3.27 Lit

=7.8634 Lit

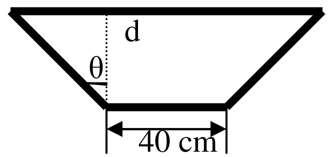
Mass of evaporated water =7.8634*1.0 kg/Lit

=7.8634 kg

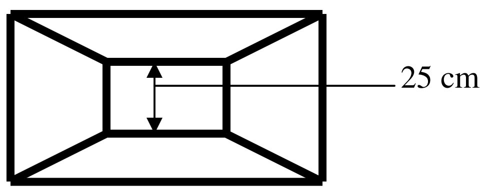


3. Analysis of Dil-20

Density of the brine=1034 kg/m^3



$\theta=15^O$ depth=d=19.5 cm=0.195 m



The volume with this depth

$V= (0.40+(d) \tan (15^O)) \times (0.25+(d) \tan (15^O)) \times (d)$

$= (0.40+(0.195) \tan (15^O)) \times (0.25+(0.195) \tan (15^O)) \times (0.195)$

$= 0.026655 \text{ m}^3$

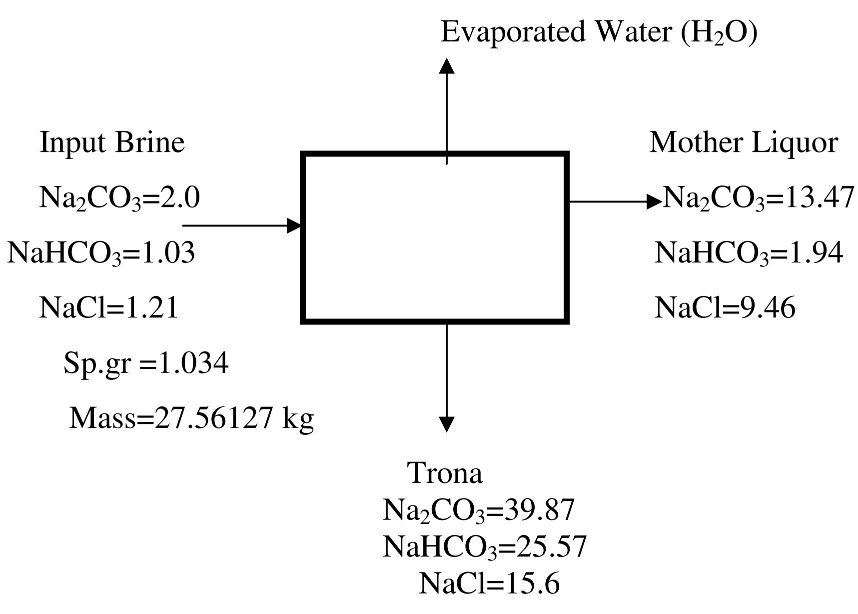
= 26.655 Lit

The mass of brine with this depth

Mass=Density * Volume

$=1034 \text{Kg/m}^3 * 0.026655 \text{m}^3$

=27.56127 kg



Mass of **Mother Liquor** and **Trona** calculated using component balance

Mass of mother liquor = 2.4231 kg

Mass of Trona =0.6684 kg

Mass of evaporated

Volume of the remaining product

Remaining depth=2.4 cm=0.024 m

$V= (0.40+ (d) \tan (15^{O})) \times (0.25+ (d) \tan (15^{O})) \times (d)$

$= (0.40+ (0.024) \tan (15^{O})) \times (0.25+ (0.024) \tan (15^{O})) \times (0.024)$

$= 0.002501\ m^3$

= 2.501 Lit

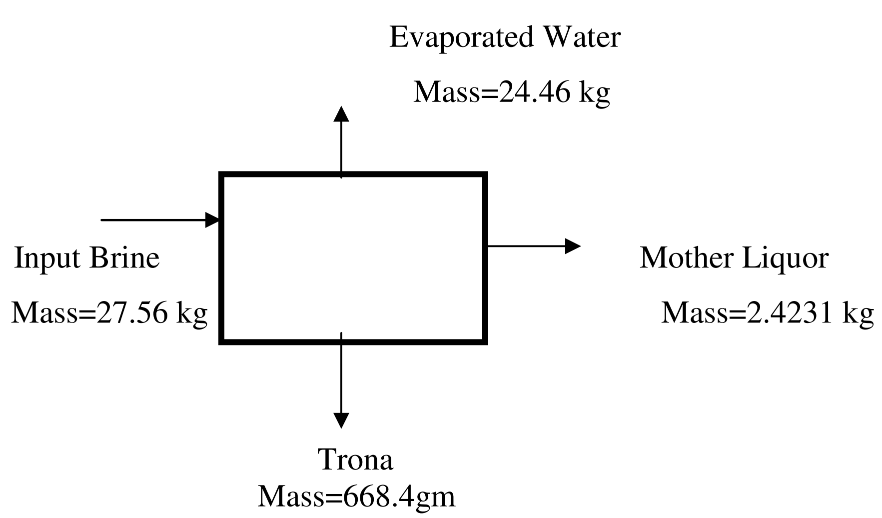
Volume of evaporated water = Total Volume - Remaining Volume

= 26.655 Li - 2.501 Lit

=24.154 Lit

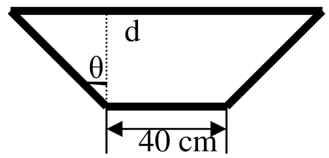
Mass of evaporated water =24.154 Lit *1.0 kg/Lit

=24.154 kg

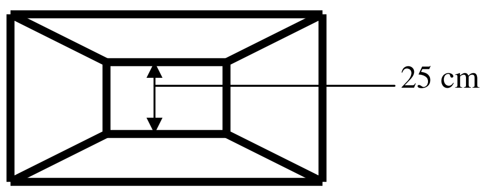


4. Analysis of Con-20

Density of the brine=1110 kg/m^3



$\theta=15^O$ depth=d=19.5 cm=0.195 m



The volume with this depth

$$V= (0.40+ (d) \tan (15^O)) \times (0.25+(d) \tan (15^O)) \times (d)$$

$$= (0.40+ (0.195) \tan (15^O)) \times (0.25+(0.195) \tan (15^O)) \times (0.195)$$

$$= 0.026655\ m^3$$

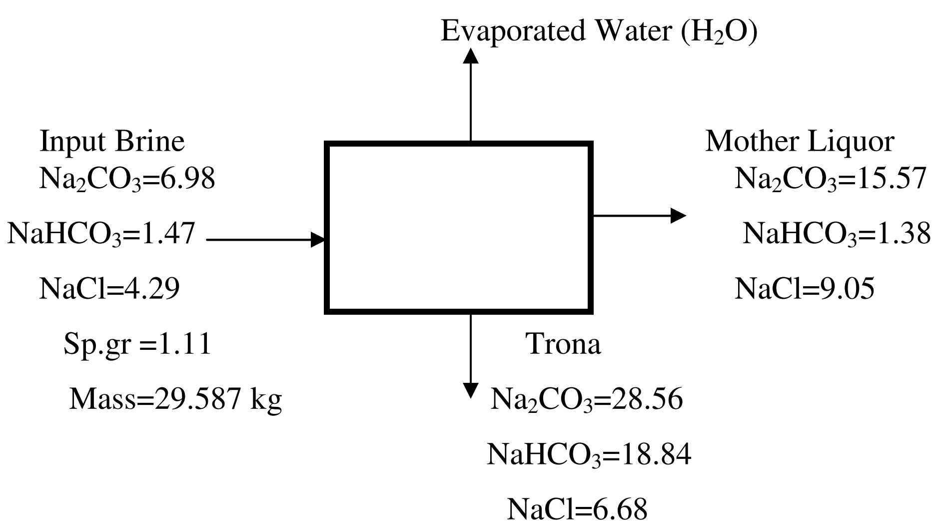
$$= 26.655\ \text{Lit}$$

The mass of brine with this depth

Mass=Density * Volume

$=1110 Kg/m^3 * 0.026655\ m^3$

=29.587 kg



Mass of **Mother Liquor** and **Trona** calculated using component balance

Mass of mother liquor = 10.43 kg

Mass of Trona =1.5445 kg

Mass of evaporated

Volume of the remaining product

Remaining depth=7.0 cm=0.07 m

$V= (0.40+(d) \tan (15^{O})) \times (0.25+(d) \tan (15^{O})) \times (d)$

$= (0.40+(0.07) \tan (15^{O})) \times (0.25+(0.07) \tan (15^{O})) \times (0.07)$

$= 0.007878 \text{ m}^3$

= 7.8781 Lit

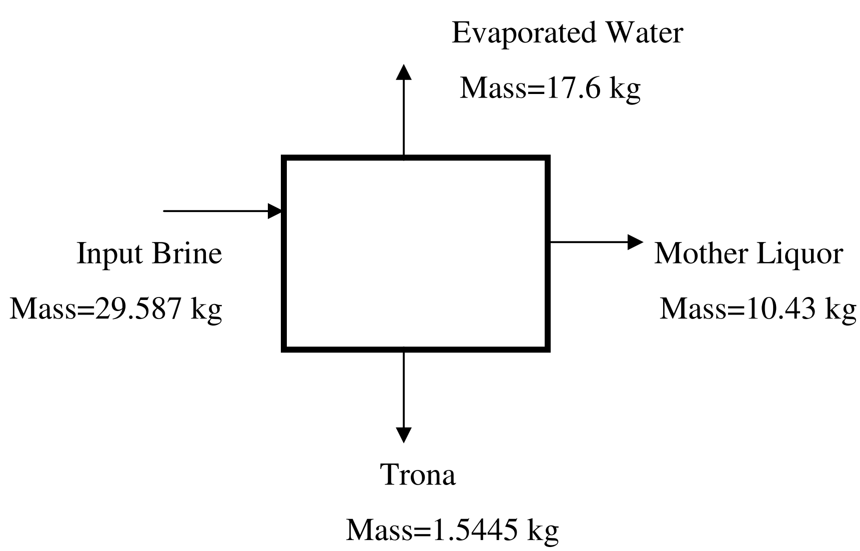
Volume of evaporated water = Total Volume - Remaining Volume

= 26.655 Lit - 7.878 Lit

=18.777 Lit

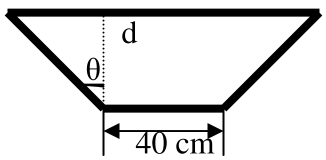
Mass of evaporated water =18.777 Lit *1.0 kg/Lit

=18.777 kg

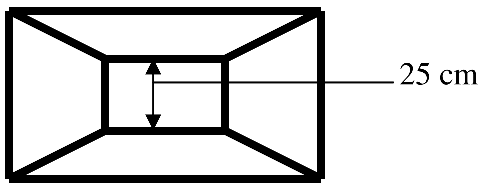


5. Analysis of Dil-25

Density of the brine=1034 kg/m^3



$\theta=15^{O}$ depth=d=24.5 cm =0.245 m



The volume with this depth

$V= (0.40+(d) \tan (15^{O})) \times (0.25+(d) \tan (15^{O})) \times (d)$

$= (0.40+(0.245) \tan (15^{O})) \times (0.25+(0.245) \tan (15^{O})) \times (0.245)$

$= 0.03601\ m^3$

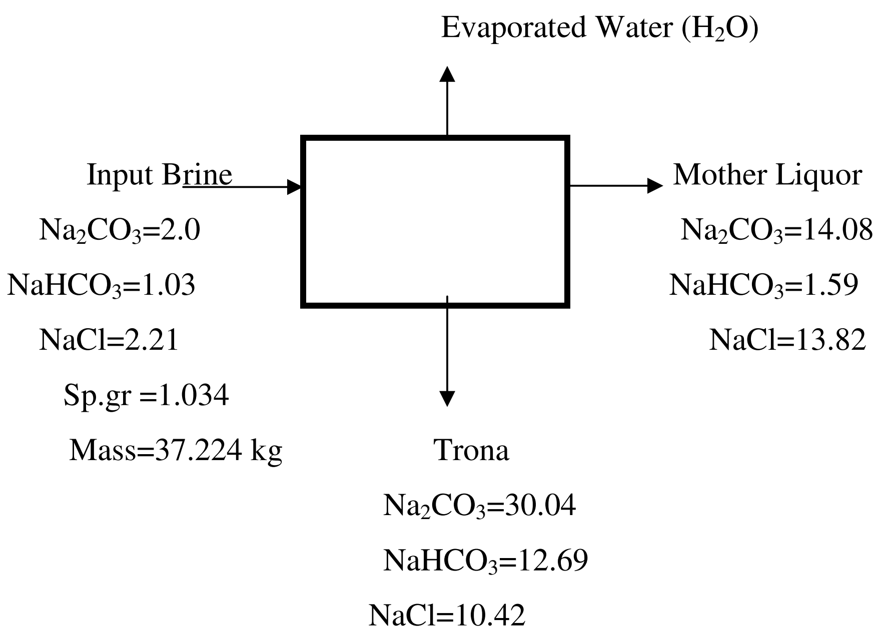
= 36.01 Lit

The mass of brine with this depth

Mass=Density * Volume

$=1034 Kg/m^3 * 0.036 m^3$

=37.224 kg



Mass of **Mother Liquor** and **Trona** calculated using component balance

Mass of mother liquor = 2.1511 kg

Mass of Trona =1.4707 kg

Mass of evaporated

Volume of the remaining product

Remaining depth=3.7 cm=0.037 m

$V= (0.40+(d) \tan (15^{O})) \times (0.25+(d) \tan (15^{O})) \times (d)$

$= (0.40+(0.037) \tan (15^{O})) \times (0.25+(0.037) \tan (15^{O})) \times (0.037)$

$= 0.003942\ m^3$

= 3.9421 Lit

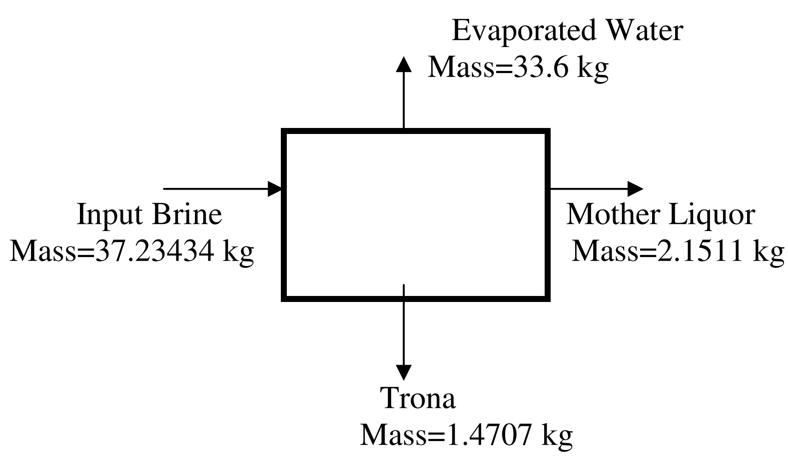
Volume of evaporated water = Total Volume - Remaining Volume

= 36.01 Lit - 3.9421 Lit

= 32.0679 Lit

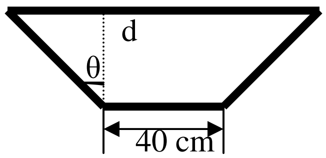
Mass of evaporated water =32.0679 Lit *1.0 kg/Lit

=32.0679 kg

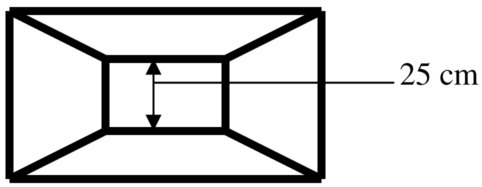


6. Analysis of Con-25

Density of the brine=1110 kg/m^3



$\theta=15^O$ depth=d=24.5 cm=0.245 m



The volume with this depth

$V= (0.40+(d) \tan (15^O)) \times (0.25+(d) \tan (15^O)) \times (d)$

$= (0.40+(0.245) \tan (15^O)) \times (0.25+(0.245) \tan (15^O)) \times (0.245)$

$= 0.03601\ m^3$

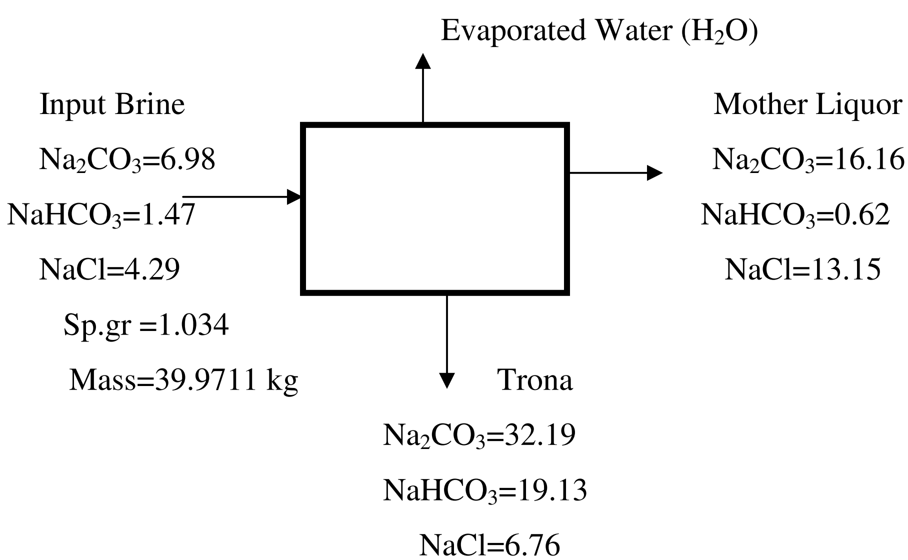
= 36.01 Lit

The mass of brine with this depth

Mass=Density * Volume

$=1110 Kg/m^3 * 0.03601 m^3$

=39.9711 kg



Mass of **Mother Liquor** and **Trona** calculated using component balance

Mass of mother liquor = 11.6 kg

Mass of Trona =2.8 kg

Mass of evaporated

Volume of the remaining product

Remaining depth=8.3 cm=0.083 m

$V= (0.40+(d) \tan (15^{O})) \times (0.25+(d) \tan (15^{O})) \times (d)$

$= (0.40+(0.083) \tan (15^{O})) \times (0.25+(0.083) \tan (15^{O})) \times (0.083)$

$= 0.009541 \text{ m}^3$

= 9.541 Lit

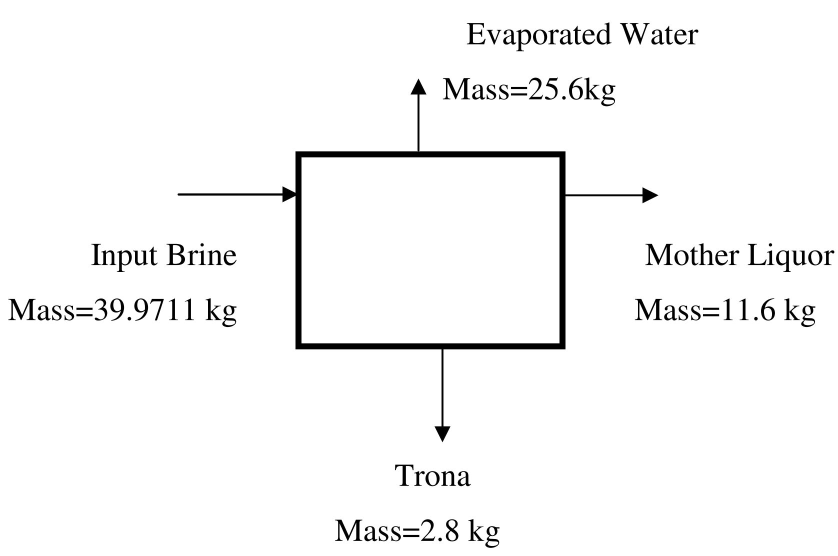
Volume of evaporated water = Total Volume - Remaining Volume

= 36.01 Lit - 9.541 Lit

= 26.469 Lit

Mass of evaporated water =26.469Lit *1.0 kg/Lit

=26.469 kg



4.2 Discussions

- As the ambient temperature increases the brine with lower depth gets hotter than the higher one.
- In the after noon when the ambient temperature goes down the brine with the lower depth gets cold faster than the hot one. On the contrary the deepest brine cools slowly which shows the chance to store energy.
- Evaporation rate shows variation from on depth to the other depth but not shows the same trend.
- The average evaporation rate of dilute and concentrated brine has little variation as shown in fig 4.3.
- The quality of Trona in the dilute brine is poor, that is it contains high percentage of sodium chloride as impurity. On the contrary Trona from concentrated brine has good quality.
- The mass of Trona obtained from concentrated brine is higher when compared with respective depth. This is obvious since the mass of the solid is higher in the concentrated one.
- The quality of Trona increases with increasing depth and concentration.
- When we mean quality of Trona
    - Less amount of chloride
    - High total alkali (carbonate and bicarbonate)
    - Coarser crystal structure
- From pan Dil-10 90% of the input brine is evaporated
- From pan Dil-20 88.75% of the input brine is evaporated
- From pan Dil-25 90.24% of the input brine is evaporated
- From pan Con-10 61.15% of the input brine is evaporated
- From pan Con-20 59.5% of the input brine is evaporated
- From pan Con-25 64% of the input brine is evaporated

The term **'solar pond'** connotes different concepts, in all of which water is heated by the absorption of solar radiation and serve as a thermal storage medium for the collected energy. As the name suggests, the salt gradient solar pond is one in which a salinity gradient is established. More specifically, over some range in depth the concentration of salt dissolved in the water (salinity) increases with depth. A salt gradient solar pond is a body of water that typically has three regions (from top to bottom) viz. surface zone, gradient zone and lower zone. The lower zone is a homogeneous, concentrated salt solution that can be either convecting or temperature stratified. Above it is the non-convective gradient zone constituting a thermally insulating layer that contains a salinity gradient such that water closer to the surface is always less salty than the water below it. The surface zone is a homogeneous layer of low salinity brine or fresh water. If the salinity gradient is large enough, there is no convection in the gradient zone even when heat is absorbed in the lower zone and on the bottom, because the hotter, saltier water at the bottom of the gradient remains denser than the colder, less salty water above it.

As water is transparent to visible light but opaque to infrared radiation, the energy in the form of sunlight that reaches the lower zone and is absorbed there can escape only via conduction. The thermal conductivity of water is moderately low, and if the gradient zone has substantial thickness, heat escapes upwards from the lower zone very slowly. This makes the solar pond both a thermal collector and a long-term storage device.

Among the three depths salinity gradient is observed in 20cm depth and 25cm depth since they have the characteristic of storing energy. This is not observed in 10cm depth evaporation pan

The effect of salinity gradient observed on Trona crystallization pond not as such significant since the concentration of the brine is low. This effect will be significant in Deca-hydrate and sodium chloride crystallization because the mother liquor from Trona crystallization and Deca-hydrate crystallization has higher concentration

Do to this the evaporation rate of the two different concentrations has no significant difference. This is clearly indicated in the average evaporation rate of dilute and concentrated brine

4.3 ''MATLAB'' Program to Compute the Daily Evaporation Rate Using Penman Equation

In order to compute the evaporation rate of the brine ''MATLAB'' program is used using penman equation based on the data obtained from meteorology service of Ethiopia

The data available are:

1. Sunshine hours
2. Daily average wind speed
3. Daily minimum and maximum temperature
4. Relative humidity of Zeway station

Parameters used in the penman equation are clearly discussed in the literature review part.

4.3.1 Evaporation Rate Computed Using Climatic Data

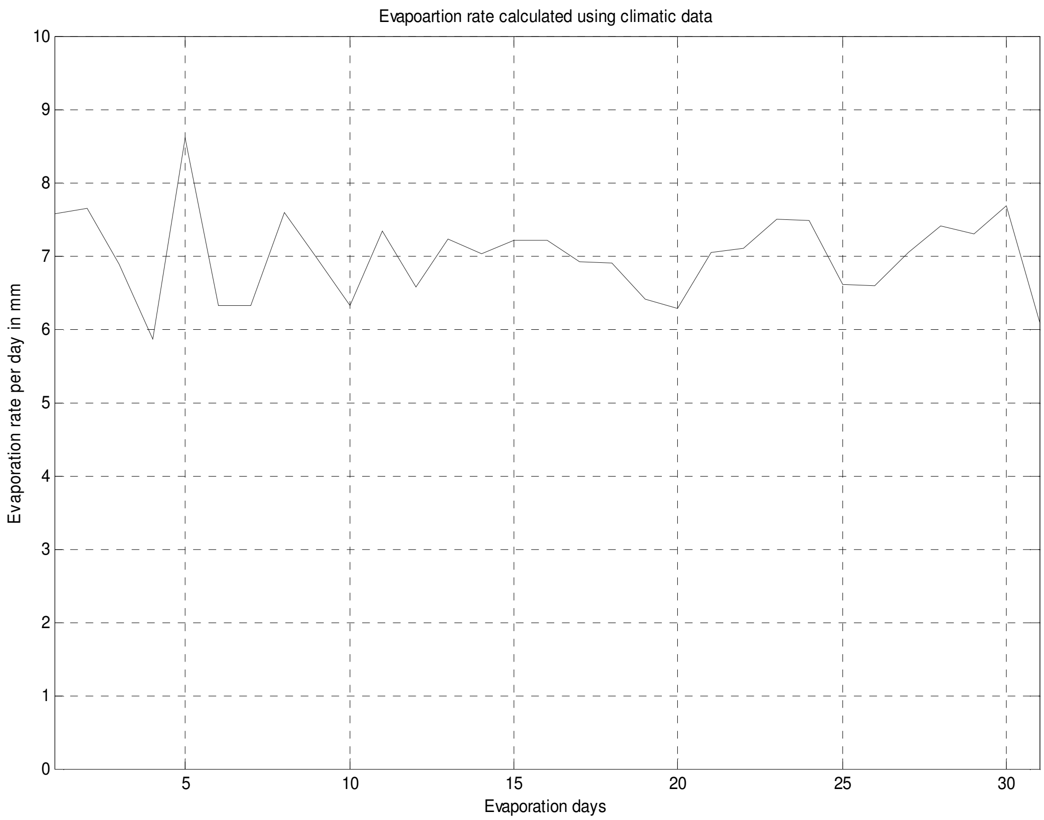


Fig 4.5 Computed evaporation rate

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Solar evaporation crystallization is on way of using solar energy for industrial sector. So it is application of alterative (renewable) energy source utilization.

- Since Abijata lake brine is very dilute the evaporation (the pre-concentration) process is energy intensive.

- Solar open evaporation process is depends on multi-parameters such as:
    - Physical chemistry of the lake brine
    - Climatic parameters
    - Atmospheric parameters

- Due to the above reason solar evaporation crystallization process is a complex process and sometimes it is an art. And also it needs close supervision and control of chemical analysis and density of the brine and the solid crystal.

- The effect of depth on the evaporation process was little

- The effect of concentration was also little

- On the 20 cm and 25 cm depth the energy storage capability of the ponds was observed

- On the 10 cm depth the energy storage capacity of the pond was not observed

- The evaporation rate computed using computer program even though it is less than the measured one it can be a good estimation
- The deviation of computed evaporation rate should be due to
    - The old climatic data used (i.e. the data collected for the last three years)
    - Empirical equation to determine net solar radiation

- The Trona obtained from deeper depth was of good quality, coarser in size and has high total alkali (i.e. high carbonate and bicarbonate and less chloride). On the contrary Trona obtained from the lowest depth is poor in quality since it contains high chloride concentration. Obviously this conclusion is from the experiment investigation.

- Even though there is no significant variation in the evaporation rate of the brine with different depth and density there is clear difference in the quality, quantity and the nature of the crystallized product (i.e. Trona). That is way solar crystallization processes is also said an art.

5.2 Recommendations and Future Works

- The conducted experimental work will form possible bases for the future work within the project and the study can be developed for other solar evaporative crystallization processes.

- Experimental work to study the economics aspect with increasing depth to obtain good quality of Trona.

- Experimental work to study salinity gradient solar pond for energy storage to mitigate the problem of waste effluent after completing the crystallization step in Abijata soda ash enterprise.

- To use solar collectors to increase the evaporation rate (i.e. to decrease the length of days for crystallization processes.

- To continue this thesis work using measuring instrument for climatic and atmospheric parameters on the site.

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Annex-A: Dilute brine temperature

Table A-1: Dilute brine temperature for the date 01-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21*	*24*	*24.5*	*26.5*	*30*	*31*	*24.5*	*22*	*24*	*25*	*25.5*				
Dil-10	*21*	*24*	*28.5*	*31.5*	*34*	*36.0*	*35*	*23*	*28*	*27*	*25*				
Dil-20	*24*	*24.5*	*27.0*	*29*	*32*	*34*	*34.3*	*32*	*30.5*	*30*	*27*				
Dil-25	*23.5*	*24.5*	*26.5*	*28.75*	*30*	*32.5*	*33*	*33*	*30*	*30*	*28*				

Table A-2: Dilute brine temperature for the date 02-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp.	*21*	*23*	*26*	*25*	*28*	*33*	*31.5*	*27.5*	*26*	*23*	*22.5*	*22.75*	*22.5*	*22*	
Dil-10	*20*	*24*	*29*	*34*	*38*	*39*	*37.5*	*34.5*	*29*	*26*	*24.5*	*22.5*	*21.75*	*20*	
Dil-20	*22*	*23.5*	*26*	*31.5*	*33*	*36*	*36.5*	*35*	*31.5*	*29*	*27.3*	*25.5*	*24*	*23*	
Dil-25	*22.5*	*23.5*	*25.5*	*29*	*31.5*	*34.5*	*35*	*34*	*31*	*29.5*	*27.5*	*26*	*24.75*	*24*	

TableA-3: Dilute brine temperature for the date 03-05-2006

Hour / Temp.(^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.5*	*24.5*	*24.5*	*29*	*29.5*	*28*	*28*	*26.5*	*31*	*25*	-----	-----	-----	-----	
Dil-10	*20.75*	*23.5*	*25*	*29.4*	*34.5*	*33*	*31.5*	*30.5*	*30*	*30*	------	------	------	------	
Dil-20	*20.5*	*23*	*24*	*26.5*	*30*	*30.5*	*30.5*	*30*	*31*	*30*	-----	-----	-----	-----	
Dil-25	*21.75*	*23*	*24*	*26*	*29*	*29.5*	*29.8*	*29.8*	*30*	*29*	------	------	------	------	

Table A-4: Dilute brine temperature for the date 04-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*19.1*	*22.5*	*23*	*27*	*27.1*	*29.9*	*31.1*	*27.1*	*27.1*	*22.5*	*23*	-----	-----	-----	
Dil-10	*19.9*	*21.5*	*27*	*29*	*35*	*39.9*	*40.0*	*33.3*	*33.3*	*26.0*	*24*	------	------	------	
Dil-20	*20*	*23.0*	*25.1*	*26.2*	*30.1*	*34.3*	*36.5*	*34.1*	*34.1*	*29.2*	*27*	-----	-----	-----	
Dil-25	*22.9*	*23.2*	*25.1*	*25.5*	*25.4*	*32.5*	*34.7*	*33.0*	*33*	*29*	*27.5*	------	------	------	

Table A-5: Dilute brine temperature for the date 05-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*23.0*	*26.0*	*28.0*	*30.0*	*35.0*	*30.2*	*28.9*	*30.0*	*26.0*	*23.0*	*21.0*	*22.8*	*21.3*	
Dil-10	*21.0*	*23.5*	*28.5*	*35.0*	*37.5*	*40.50*	*41.0*	*40.1*	*35.2*	*31.0*	*28.0*	*23.5*	*22.0*	*22.0*	
Dil-20	*22.5*	*23.75*	*26.13*	*30.5*	*33.35*	*35.75*	*38.1*	*38.9*	*37.1*	*34.8*	*32.0*	*29.0*	*26.1*	*25.2*	
Dil-25	*23.0*	*23.75*	*26.0*	*29.25*	*31.75*	*34.25*	*36.3*	*37.1*	*36.5*	*34.7*	*31.9*	*29.8*	*27.9*	*26.7*	

Table A-6: Dilute brine temperature for the date 06-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23.75*	*20.6*	*24.0*	*25.0*	------	------	*37.1*	*26.0*	*26.8*	*25.1*	*24.0*	*22.0*	*21.5*	*21.1*	
Dil-10	*21.0*	*26*	*28.5*	*31.5*	------	------	*39.5*	*29.0*	*27.5*	*26.7*	*25.1*	*23.6*	*22.0*	*20.9*	
Dil-20	*23.0*	*24.5*	*26.0*	*28.5*	-------	-------	*39.0*	*28.0*	*28.0*	*27.5*	*26.6*	*25.3*	*24.9*	*23.5*	
Dil-25	*24.0*	*25*	*26.2*	*28.0*	------	------	*38.1*	*28.1*	*28.0*	*27.3*	*26.5*	*26.1*	*25.0*	*24.0*	

Table A-7: Dilute brine temperature for the date 07-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.5*	*28.0*	*27.0*	*30.5*	*28.5*	*30.0*	*31.5*	*33.0*	*27.0*	*29.0*	*25.0*	*24.0*	*22.0*	*21.0*	
Dil-10	*20.0*	*28.75*	*31.0*	*35.0*	*38.5*	*34.0*	*36.0*	*38.5*	*31.75*	*25.5*	*24.0*	*202*	*20.0*	*19.5*	
Dil-20	*21.0*	*24.5*	*26.5*	*31.0*	*33.0*	*35.5*	*35.75*	*36.0*	*34.0*	*31.0*	*28.0*	*27.0*	*24.0*	*24.0*	
Dil-25	*21.5*	*24.5*	*26.0*	*28.5*	*31.0*	*33.75*	*34.0*	*34.5*	*33.5*	*30.0*	*29.0*	*27.0*	*25.0*	*25.0*	

Table A-8: Dilute brine temperature for the date 08-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*22.0*	*25.0*	*26.0*	*29.0*	*29.0*	*30.0*	*31.0*	*31.0*	*31.0*	*30.9*	*27.0*	*24.0*	*23.9*		
Dil-10	*20.0*	*27.0*	*32.0*	*37.0*	*39.0*	*37.0*	*39.0*	*37.5*	*32.0*	*29.0*	*25.0*	*23.6*	*22.9*		
Dil-20	*22.0*	*24.5*	*27.0*	*32.0*	*34.0*	*34.5*	*36.0*	*36.5*	*34.0*	*33.0*	*29.0*	*27.2*	*26.8*		
Dil-25	*22.0*	*24.5*	*26.5*	*30.0*	*32.0*	*33.0*	*35.0*	*35.0*	*34.0*	*33.0*	*30.0*	*28.8*	*28.3*		

Table A-9: Dilute brine temperature for the date 09-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*25.0*	*27.0*	*28.0*	*29.5*	*30.0*	*31.0*	*32.0*	*31.5*	*30.0*	*26.0*	*23.0*	*25.0*	*24.0*	
Dil-10	*20.0*	*25.1*	*31.0*	*36.0*	*41.0*	*41.1*	*38.0*	*33.0*	*29.0*	*24.0*	*22.0*	*20.0*	*19.0*	*18.0*	
Dil-20	*21.0*	*24.0*	*26.1*	*30.0*	*34.0*	*37.0*	*37.0*	*34.0*	*32.0*	*29.5*	*27.0*	*24.0*	*22.5*	*22.0*	
Dil-25	*23.0*	*24.0*	*26.0*	*29.1*	*33.3.*	*35.1*	*35.0*	*33.0*	*32.0*	*29.0*	*27.5*	*25.0*	*24.0*	*23.0*	

Table A-10: Dilute brine temperature for the date 10-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*24.0*	*28.0*	*29.0*	*29.0*	*28.0*	*31.0*	-----	*26.0*	*25.5*	*25.0*	*19.0*	*21.5*	*20.0*	
Dil-10	*20.2*	*27.0*	*33.5*	*38.0*	*41.0*	*26.7*	*36.5*	-----	*27.75*	*25.0*	*23.0*	*21.0*	*20.0*	*19.0*	
Dil-20	*21.0*	*23.5*	*27.0*	*31.0*	*35.0*	*37.0*	*34.0*	-----	*31.5*	*29.0*	*27.5*	*25.5*	*24.0*	*23.5*	
Dil-25	*22.0*	*23.0*	*25.5*	*29.0*	*32.1*	*33.0*	*33.0*	-----	*31.0*	*29.5*	*28.0*	*26.0*	*25.0*	*24.0*	

Table A-11: Dilute brine temperature for the date 11-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*26.1*	*26.5*	*29.0*	*30.0*	*33.0*	*29.5*	*32.0*	*32.0*	*29.0*	*27.0*	*25.0*	*23.5*	*23.5*	
Dil-10	*23.9*	*30.9*	*33.0*	*39.1*	*40.0*	*36.5*	*32.3*	*33.0*	*26.0*	*23.0*	*21.5*	*21.0*	*19.0*	*19.0*	
Dil-20	*23.0*	*25.5*	*28.0*	*31.1*	*35.0*	*34.9*	*33.5*	*34.5*	*30.0*	*26.2*	*24.0*	*22.0*	*20.5*	*20.0*	
Dil-25	*22.9*	*24.8*	*26.6*	*29.5*	*32.5*	*32.9*	*32.5*	*33.5*	*30.0*	*26.5*	*24.5*	*22.5*	*21.0*	*20.3*	

Table A-12: Dilute brine temperature for the date 12-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*26.0*	*26.5*	-------	*29.75*	*29.0*	*29.0*	*31.5*	*34.0*	*33.0*	*30.5*	*28.0*	*20.0*	*24.0*	*21.0*	
Dil-10	*20.0*	*25.5*	-------	*39.0*	*52.0*	*49.0*	*34.0*	----	----	----	----	-----	-----	----	
Dil-20	*20.0*	*22.5*	-------	*29.0*	*32.5*	*33.75*	*30.5*	*29.5*	*27.5*	*25.0*	*23.0*	*21.0*	*19.5*	*19.0*	
Dil-25	*20.0*	*21.5*	------	*27.0*	*30.0*	*31.0*	*29.0*	*28.5*	*27.0*	*25.0*	*23.0*	*22.0*	*20.2*	*20.0*	

Table A-13: Dilute brine temperature for the date 13-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*24.9*	*26.0*	*26.1*	*30.3*	*31.0*	------	------	*25.0*	*27.8*	*25.5*	*20.0*			
Dil-10	-----	-------	-------	------	----	------	-----	-----	-------	------	----	------			
Dil-20	*20.0*	*22.0*	*27.5*	*32.5*	*36.1*	*37.1*	-------	-------	*30.1*	*27.0*	*26.0*	*25.0*			
Dil-25	*19.9*	*21.5*	*25.9*	*29.0*	*32.5*	*34.5*	------	------	*30.0*	*28.1*	*27.1*	*26.5*			

Table A-14: Dilute brine temperature for the date 14-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23.0*	*27.0*	*30.0*	*29.0*	*32.0*	*33.0*	*31.0*	*29.0*	*33.0*	*33.0*	*27.0*	*25.0*	*23.0*	*22.0*	
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*21.0*	*25.0*	*28.1*	*32.5*	*36.0*	*38.0*	*36.5*	*34.0*	*33.5*	*32.0*	*29.0*	*27.0*	*28.0*	*27.0*	
Dil-25	*21.5*	*23.2*	*26.5*	*30.0*	*33.0*	*35.5*	*35.5*	*33.2*	*33.5*	*32.5*	*30.0*	*28.0*	*25.0*	*24.5*	

Table A-15: Dilute brine temperature for the date 15-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*22.5*	*22.0*	*26.0*	*29.0*	*31.5*	*32.0*	*35.0*	*33.0*	*32.5*	*31.0*	*29.5*	*22.0*	*25.0*	*33.0*	
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*22.0*	*25.5*	*30.0*	*34.0*	*38.0*	*39.0*	*36.0*	*36.3*	*35.0*	*33.0*	*29.0*	*26.5*	*25.0*	*24.0*	
Dil-25	*22.0*	*24.0*	*28.0*	*31.5*	*35.0*	*36.0*	*35.5*	*36.5*	*35.0*	*33.2*	*30.0*	*28.0*	*26.0*	*25.5*	

Table A-16: Dilute brine temperature for the date 16-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23.5*	*25.0*	*28.0*	*31.5*	*33.0*	*32.7*	*28.5*	*25.5*	*31.5*	*29.0*	*26.0*	*23.0*	*22.4*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*22.0*	*24.75*	*29.0*	*34.5*	*38.3*	*38.0*	*38.5*	*32.1*	*32.5*	*31.5*	*27.1*	*24.5*	*23.1*		
Dil-25	*23.0*	*24.2*	*27.5*	*31.75*	*35.0*	*36.0*	*35.3*	*32.5*	*32.0*	*31.2*	*28.0*	*25.5*	*24*		

Table A-17: Dilute brine temperature for the date 17-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*230*	*27.5*	*25.0*	*30.5*	*30.3*	*33.0*	*32.0*	*34.0*	*31.0*	*30.0*	*25.0*	*25.0*	*24.8*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*20.5*	*25.0*	*28.5*	*34.0*	*38.0*	*41.0*	*39.0*	*37.0*	*35.0*	*32.5*	*29.0*	*27.1*	*25.1*		
Dil-25	*21.3*	*23.0*	*26.5*	*31.0*	*35.0*	*39.0*	*37.5*	*36.0*	*34.9*	*33.1*	*30.5*	*29.5*	*27.0*		

Table A-18: Dilute brine temperature for the date 18-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.5*	*25.1*	*28.0*	*30.5*	*31.0*	*32.1*	*33.0*	*33.0*	*32.5*	*30.0*	*28.5*	*24.0*	*23.0*	*21.0*	
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*23.0*	*26.0*	*30.1*	*35.1*	*35.0*	*34.0*	*33.0*	*35.75*	*27.0*	*24.0*	*23.0*	*21.5*	*21.0*	*20.0*	
Dil-25	*23.1*	*25.1*	*28.2*	*32.0*	*33.0*	*32.0*	*31.5*	*28.8*	*27.0*	*24.3*	*23.0*	*22*	*21.5*	*20.5*	

Table A-19: Dilute brine temperature for the date 19-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*22.9*	*28.0*	*32.2*	*32.5*	*31.5*	*33.5*	*34.0*	*34.2*	*29.5*	*30.0*	*28.5*	*23.1*	*23.0*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*21.0*	*25.5*	*31.0*	*36.5*	*39.0*	*38.1*	*37.0*	*37.2*	*29.9*	*28.8*	*26.1*	*24.5*	*22.8*		
Dil-25	*21.1*	*23.8*	*27.5*	*31.5*	*35.1*	*35.2*	*35.2*	*35.2*	*30.0*	*29.1*	*27.2*	*26.1*	*23.5*		

Table A-20 Appendix A: Dilute brine temperature for the date 20-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23*	*25*	*27.5*	*27*	*30.0*	*33.5*	*31.0*	*32.0*	*31.0*	*30.5*	*30.3*	*25.8*	*24.5*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*21.5*	*25.0*	*30.0*	*34.0*	*36.5*	*38.5*	*35.1*	*34.5*	*30.1*	*26.0*	*24.9*	*23.1*	*21.9*		
Dil-25	*20.75*	*23*	*26.5*	*30.0*	*33.0*	*35.5*	*34.5*	*33.5*	*29.9*	*25.5*	*25.0*	*24.2*	*22.5*		

Table A-21: Dilute brine temperature for the date 21-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*26*	*28*	*28.2*	*30.0*	*30.5*	*29.5*	*33.0*	*30.0*	*32.0*	*27.5*	*25.0*	*24.3*	*24.0*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*26.5*	*27.75*	*32.0*	*35.0*	*38.5*	*35.0*	*36.0*	*33.1*	*31.5*	*29.0*	*24.9*	*23.1*	*22.9*		
Dil-25	*20.5*	*24.0*	*28.0*	*31.0*	*34.5*	*34.0*	*34.1*	*32.9*	*31.3*	*27.1*	*25.1*	*24.0*	*23.5*		

Table A-22: Dilute brine temperature for the date 22-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*25.0*	*27.0*	*27.0*	*28.5*	*31.5*	*33.0*	*33.1*	*35.0*	*31.0*	*27.0*	*24.1*	*23.5*	*23.3*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*22.0*	*25.0*	*29.0*	*37.0*	*40.0*	*45.0*	*52.0*	*54.5*	*49.0*	*37.0*	*30.5*	*27.5*	*25.1*		
Dil-25	*21.75*	*23.5*	*26.0*	*32.5*	*36.0*	*39.0*	*39.0*	*37.5*	*35.0*	*30.0*	*28.0*	*25.1*	*24.0*		

Table A-23: Dilute brine temperature for the date 23-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.2*	*23.9*	*24.9*	*29.5*	*30.5*	*29.9*	*32.5*	*29.0*	--	*24.0*	*22.5*				
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	*22.1*	*23.5*	*25.0*	*31.1*	*38.5*	*39.9*	*43.0*	*41.0*	--	*29.5*	*27.2*				
Dil-25	*22.5*	*23.1*	*24.1*	*29.1*	*35.0*	*37.9*	*39.0*	*34.0*	--	*29.5*	*27.0*				

Table A-24: Dilute brine temperature for the date 24-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.0*	*23.0*	*27.0*	*27.0*	*31.0*	*29.2*	*29.5*	*30.2*	*30.3*	*29.0*	*25.0*	*23.0*	*23.0*	*22.0*	
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-25	*22.0*	*23.0*	*28.2*	*31.0*	*34.0*	*36.75*	*36.0*	*32.0*	*31.0*	*28.0*	*24.0*	*21.0*	*20.0*	*19.0*	

Table A-25: Dilute brine temperature for the date 25-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.0*	*27.0*	*28.0*	*28.5*	*31.0*	*32.0*	*31.5*	*35.5*	*32.0*	*30.5*	*25.5*	*23.0*	*21.0*	*20.5*	
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-25	*19.75*	*22.3*	*29.0*	*35.5*	*39.5*	*40.0*	*42.0*	*40.0*	*34.75*	*30.0*	*24.5*	*22.5*	*22.0*	*21.5*	

Table A-26: Dilute brine temperature for the date 26-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.0*	*22.2*	*27.5*	*29.0*	*31.0*	*29.5*	*33.5*	*32.1*	*34.0*	*30.5*	*27.5*	*29.9*			
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-25	*21.0*	*22.0*	*25.5*	*32.0*	*38.0*	*40.0*	*42.5*	*42.1*	*37.5*	*33.1*	*29.1*	*26.5*			

Table A-27: Dilute brine temperature for the date 27-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.5*	*25.5*	*29.9*	*30.1*	*32.5*	*30.5*	*33.1*	*34.1*	--	*28.0*	*26.5*	*25.0*	*23.0*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-25	*22.5*	*23.9*	*30.0*	*36.5*	*41.5*	*41.0*	*41.9*	*38.1*	--	*37.1*	*34.0*	*31.5*	*28.1*		

Table A-28: Dilute brine temperature for the date 28-05-2006

Hour Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23.5*	*27.0*	*27.5*	*29.0*	*31.5*	*35.0*	*33.5*	*31.5*	*33.0*	*30.5*	*27.5*	*24.0*	*22.5*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-25	*20.5*	*24.5*	*28.0*	*35.0*	*41.0*	*42.7*	*47.5*	*51.0*	*48.5*	*45.0*	*42.0*	*38.0*	*34.5*		

Table A-29: Dilute brine temperature for the date 29-05-2006

Hour Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.5*	*25.0*	*28.5*	*31.0*	*31.5*	*32.5*	*33.0*	*33.5*	*34.75*	*29.5*	*27.5*	*25.0*	*22.5*		
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-25	*23.5*	*25.1*	*30.0*	*35.1*	*41.0*	*44.0*	*48.0*	*52.5*	*41.5*	*32.0*	*28.0*	*25.5*	*23.0*		

Table A-30: Dilute brine temperature for the date 30-05-2006

Hour Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*22.0*	*26.0*	*26.0*	*28.5*	*29.0*	*30.5*	*32.0*	*33.5*	*31.9*	*27.5*	-----	------	-----	------	
Dil-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Dil-25	*21.0*	*25.0*	*25.0*	*31.0*	*38.0*	*44.0*	*39.5*	*40.1*	*43.0*	*33.5*	-----	------	-----	------	

Annex- B: Dilute brine depth

Table B-1: Dilute brine depth for the date 01-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*9.0*	*8.7*	*8.5*	*8*		
Dil-20	*19.0*	*19.8*	*18.5*	*18.1*		
Dil-25	*24.0*	*23.9*	*23.5*	*23.1*		

Table B-2: Dilute brine depth for the date 02-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*8*	*8*	*7.4*		7.3	
Dil-20	*18.1*	*18*	*17.6*		17.5	
Dil-25	*23.1*	*23*	*22.7*		22.6	

Table B-3: Dilute brine depth for the date 03-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*7.3*		*6.8*	*6.8*		
Dil-20	*17.5*		*17*	*17*		
Dil-25	*22.6*		*22.2*	*22.1*		

Table B-4: Dilute brine depth for the date 04-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*6.8*			*6.2*		
Dil-20	*17*			*16.3*		
Dil-25	*22.1*			*21.4*		

Table B-5: Dilute brine depth for the date 05-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*6.2*	*6.0*	*5.6*	*5.3*	*5.5*	
Dil-20	*16.3*	*16.0*	*15.9*	*15.6*	*15.6*	
Dil-25	*21.4*	*21.2*	*20.9*	*20.8*	*20.7*	

Table B-6: Dilute brine depth for the date 06-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*5.5*	--------	*5.3*	*5.2*	*5.2*	
Dil-20	*15.6*	--------	*15.2*	*15.2*	*15.2*	
Dil-25	*20.7*	--------	*20.6*	*20.6*	*20.4*	

Table B-7: Dilute brine depth for the date 07-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*5.2*	*5.0*	*4.9*	*4.6*	*4.6*	
Dil-20	*15.2*	*15.2*	*15.0*	*14.7*	*14.6*	
Dil-25	*20.4*	*20.4*	*20.3*	*19.8*	*19.8*	

Table B-8: Dilute brine depth for the date 08-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*4.6*	*4.4*	*4.2*	*4.1*	*3.9*	
Dil-20	*14.6*	*14.5*	*14.3*	*14.0*	*13.9*	
Dil-25	*19.8*	*19.5*	*19.3*	*19.2*	*19.1*	

Table B-9: Dilute brine depth for the date 09-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*3.9*	*3.5*	*3.2*	*3.0*	*3.0*	
Dil-20	*13.9*	*13.7*	*13.5*	*13.1*	*13.0*	
Dil-25	*19.1*	*18.9*	*18.4*	*18.4*	*18.2*	

Table B-10: Dilute brine depth for the date 10-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*3.0*	*2.5*	*2.4*	*2.4*	*2.3*	
Dil-20	*13.0*	*12.9*	*12.5*	*12.5*	*12.3*	
Dil-25	*18.2*	*17.7*	*17.7*	*17.7*	*17.5*	

Table B-11: Dilute brine depth for the date 11-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*2.3*	*2.1*	*1.9*	*1.7*	*1.6*	
Dil-20	*12.3*	*12.2*	*12.0*	*11.6*	*11.5*	
Dil-25	*17.5*	*17.4*	*17.4*	*16.8*	*16.7*	

Table B-12: Dilute brine depth for the date 12-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	*1.6*	*1.6*	-----	----	-------	
Dil-20	*11.5*	*11.4*	*10.9*	*10.7*	*10.6*	
Dil-25	*16.7*	*16.4*	*16.1*	*15.8*	*15.7*	

Table B-13: Dilute brine depth for the date 13-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	-------	-------	-------	-------	--------	
Dil-20	*10.6*	*10.4*	--	*10.1*	*9.8*	
Dil-25	*15.7*	*15.5*	--	*15.2*	*15.1*	

Table B-14: Dilute brine depth for the date 14-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*9.8*	*9.7*	*9.3*	*9.1*	*9.1*	
Dil-25	*15.1*	*14.9*	*14.4*	*14.3*	*14.2*	

Table B-15: Dilute brine depth for the date 15-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*9.1*	*8.9*	*8.6*	*8.3*	*8.3*	
Dil-25	*14.2*	*14.0*	*13.8*	*13.5*	*13.5*	

Table B-16: Dilute brine depth for the date 16-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*8.3*	*8.1*	*8.0*	*7.9*	*7.6*	
Dil-25	*13.5*	*13.3*	*13.1*	*13.0*	*12.8*	

Table B-17: Dilute brine depth for the date 17-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*7.6*	*7.6*	*7.3*	*7.1*	*7.0*	
Dil-25	*12.8*	*12.7*	*12.5*	*12.4*	*12.3*	

Table B-18: Dilute brine depth for the date 18-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*7.0*	*6.7*	*6.3*	*5.9*	*5.9*	
Dil-25	*12.3*	*12.1*	*11.4*	*11.2*	*11.2*	

Table B-19: Dilute brine depth for the date 19-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*5.9*	*5.8*	*5.4*	*5.2*	*5.0*	
Dil-25	*11.2*	*11.1*	*10.8*	*10.4*	*10.2*	

Table B-20: Dilute brine depth for the date 20-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*5.0*	*4.9*	*4.8*	*4.6*	*4.3*	
Dil-25	*10.2*	*10.1*	*9.9*	*9.7*	*9.5*	

Table B-21: Dilute brine depth for the date 21-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*4.3*	*4.0*	*3.9*	*3.9*	*3.6*	
Dil-25	*9.5*	*9.1*	*9.1*	*8.9*	*8.8*	

Table B-22: Dilute brine depth for the date 22-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*3.6*	*3.5*	*3.4*	*3.4*	*3.2*	
Dil-25	*8.8*	*8.7*	*8.5*	*8.5*	*8.3*	

Table B-23: Dilute brine depth for the date 23-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	*3.2*	*3.1*	*2.8*	*2.4*		
Dil-25	*8.3*	*8.1*	*7.5*	*7.5*	*7.3*	

Table B-24: Dilute brine depth for the date 24-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	--	--	--	--	--	
Dil-25	*7.3*	*7.25*	*7.0*	*6.8*	*6.7*	

Table B-25: Dilute brine depth for the date 25-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	--	--	--	--	--	
Dil-25	*6.7*	*6.6*	*6.3*	*5.9*	*5.9*	

Table B-26: Dilute brine depth for the date 26-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	--	--	--	--	--	
Dil-25	*5.9*	*5.8*	*5.7*	*5.5*	*5.5*	

Table B-27: Dilute brine depth for the date 27-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	--	--	--	--	--	
Dil-25	*5.5*	*5.3*	*5.2*	*5.1*	*5.0*	

Table B-28: Dilute brine depth for the date 28-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	--	--	--	--	--	
Dil-20	--	--	--	--	--	
Dil-25	*5.0*	*4.9*	*4.8*	*4.7*	*4.6*	

Table B-29: Dilute brine depth for the date 29-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	------	-----	------	------	-----	
Dil-20	------	-----	-----	-----	-----	
Dil-25	*4.6*	*4.5*	*4.5*	*4.3*	*4.1*	

Table B-30: Dilute brine depth for the date 30-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Dil-10	-----	-----	-----	-----	-----	
Dil-20	-----	-----	-----	-----	-----	
Dil-25	*4.1*	*3.8*	*3.7*	-----	-----	

Annex-C: Concentrate brine temperature

Table C-1: Concentrated brine temperature for the date 01-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21*	*24*	*24.5*	*26.5*	*30*	*31*	*24.5*	*22*	*24*	*25*	*25.5*				
Con-10	*21.5*	*24*	*28.5*	*32*	*34*	*36.5*	*35*	*33*	*29*	*29*	*25.5*				
Con-20	*24*	*24.5*	*28*	*30*	*32*	*34.5*	*35*	*33.5*	*31*	*30*	*27.5*				
Con-25	*23*	*24.5*	*26.5*	*29*	*31*	*32*	*33.5*	*33*	*31*	*30*	*28*				

Table C-2: Concentrated brine temperature for the date 02-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21*	*23*	*26*	*25*	*28*	*33*	*31.5*	*27.5*	*26*	*23*	*22.5*	*22.75*	*22.5*	*22*	
Con-10	*21*	*24.5*	*29*	*33*	*37*	*38.5*	*37*	*34.5*	*29.5*	*26*	*25*	*23*	*21.5*	*19.5*	
Con-20	*23*	*24.5*	*26.5*	*30.5*	*33*	*36.5*	*36.5*	*35*	*32*	*29*	*28*	*26.5*	*24.8*	*22.5*	
Con-25	*23.5*	*24.5*	*27*	*30.5*	*32*	*35*	*35*	*34.5*	*32*	*30*	*28.5*	*27*	*25.5*	*23.25*	

Table C-3: Concentrated brine temperature for the date 03-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	21.5	24.5	24.5	29	29.5	28	28	26.5	31	25	-----	-----	-----	-----	
Con-10	21.5	24	25	29	34.5	33	31.75	30.5	30.5	30	------	------	------	------	
Con-20	21.9	23	24	26.5	30	31	30.2	30.2	30.3	30	-----	-----	-----	-----	
Con-25	22.3	23	24.8	26	29	30	29.5	29.5	30	30	------	------	------	------	

Table C-4: Concentrated brine temperature for the date 04-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	19.1	22.5	23.0	27	27.1	29.9	31.1	27	25.1	22.5	23	-----	-----	-----	
Con-10	20.0	22.0	27	26.5	34.9	38.5	40.1	34	29.9	26.3	24	------	------	------	
Con-20	22.8	23.1	25.2	26.3	30.9	33.6	36.4	34.1	31.6	29.5	27.4	-----	-----	-----	
Con-25	23	23.6	25.1	25.5	29.9	32.0	34.6	33	31	29.0	27.1	------	------	------	

Table C-5: Concentrated brine temperature for the date 05-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	21.0	23.0	26.0	28.0	30.0	30.5	30.2	28.9	30.0	26.0	23.0	*21.0*	*22.8*	*21.3*	
Con-10	20.2	23.5	28.63	35.0	38.25	40.5	42.0	41.9	37.3	33.1	29.0	*25.1*	*23.1*	*22.6*	
Con-20	22.0	23.48	25.75	30.13	32.87	35.4	38.0	35.7	37.0	34.9	31.8	*28.9*	*27.3*	*26.1*	
Con-25	22.5	23.75	25.75	29.35	31.5	33.75	36.5	37.4	36.1	34.1	31.6	*28.8*	*27.5*	*27.5*	

Table C-6: Concentrated brine temperature for the date 06-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23.75*	*20.6*	*24.0*	*25.0*	------	-------	*37.1*	*26.0*	*26.8*	*25.1*	*24.0*	*22.0*	*21.5*	*21.1*	
Con-10	*21.0*	*25.5*	*28.5*	*31.0*	-------	-------	*30.3*	*29.1*	*27.2*	*27.0*	*25.5*	*24.8*	*23.1*	*21.9*	
Con-20	*23.5*	*24.5*	*26.5*	*28.0*	-------	-------	*39.1*	*28.8*	*27.8*	*28.0*	*27.0*	*26.1*	*24.8*	*24.0*	
Con-25	*24.0*	*25.0*	*26.2*	*28.0*	-------	-------	*38.2*	*26.5*	*27.1*	*28.0*	*27.1*	*26.5*	*25.3*	*24.7*	

Table C-7: Concentrated brine temperature for the date 07-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.5*	*28.0*	*27.0*	*30.5*	*28.5*	*30.0*	*31.5*	*33.0*	*27.0*	*29.0*	*25.0*	*24.0*	*22.0*	*21.0*	
Con-10	*20.3*	*27.5*	*27.0*	*36.5*	*39.5*	*40.0*	*39.5*	*39.0*	*35.0*	*30.0*	*27.0*	*25.0*	*22.5*	*20.2*	
Con-20	*21.5*	*25.75*	*27.0*	*30.0*	*33.0*	*35.5*	*35.75*	*36.0*	*35.0*	*31.0*	*29.0*	*27.5*	*22.5*	*25.0*	
Con-25	*21.75*	*25.0*	*31.0*	*29.5*	*32.0*	*33.75*	*34.0*	*34.5*	*33.5*	*31.0*	*30.0*	*28.0*	*26.0*	*26.0*	

Table C-8: Concentrated brine temperature for the date 08-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*22.0*	*25.0*	*26.0*	*29.0*	*29.0*	*30.0*	*31.0*	*31.0*	*31.0*	*30.9*	*27.0*	*24.0*	*23.9*		
Con-10	*21.0*	*26.5*	*31.0*	*37.0*	*42.0*	*40.0*	*50.0*	*54.0*	*50.0*	*45.0*	*35.0*	*29.3*	*23.9*		
Con-20	*22.5*	*25.0*	*27.5*	*31.0*	*34.0*	*34.5*	*37.0*	*38.3*	*36.0*	*34.0*	*31.0*	*29.5*	*26.8*		
Con-25	*23.0*	*24.5*	*27.0*	*30.0*	*31.0*	*33.2*	*35.0*	*36.0*	*35.0*	*33.0*	*32.0*	*28.9*	*28.5*		

Table C-9: Concentrated brine temperature for the date 09-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*25.0*	*27.0*	*28.0*	*29.5*	*30.0*	*31.0*	*32.0*	*31.5*	*30.0*	*26.0*	*23.0*	*25.0*	*24.0*	
Con-10	*21.0*	*25.0*	*30.0*	*34.0*	*45.0*	*49.0*	*37.5*	*47.0*	*31.0*	*32.0*	*26.0*	*23.0*	*20.0*	*19.5*	
Con-20	*22.0*	*24.2*	*27.0*	*31.1*	*35.0*	*36.1*	*38.0*	*35.0*	*33.0*	*31.0*	*28.0*	*25.0*	*24.0*	*23.75*	
Con-25	*23.0*	*24.0*	*26.0*	*29.0*	*32.0*	*35.0*	*35.0*	*35.0*	*33.0*	*31.0*	*28.5*	*26.0*	*25.0*	*24.5*	

Table C-10: Concentrated brine temperature for the date 10-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*24.0*	*28.0*	*29.0*	*29.0*	*28.0*	*31.0*	-----	*26.0*	*25.5*	*25.0*	*19.0*	*21.5*	*20.0*	
Con-10	*20.0*	*26.0*	*31.0*	*36.1*	*38.0*	*38.0*	*34.0*	-----	*29.0*	*26.5*	*25.0*	*22.5*	*21.75*	*21.0*	
Con-20	*21.5*	*24.0*	*27.0*	*31.0*	*35.0*	*35.0*	*34.0*	----	*32.75*	*30.5*	*28.5*	*26.0*	*25.0*	*24.5*	
Con-25	*22.0*	*23.5*	*26.0*	*28.1*	*32.0*	*33.0*	*33.0*	-----	*32.0*	*30.5*	*29*	*27.0*	*26.0*	*25.5*	

Table C-11: Concentrated brine temperature for the date 11-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*26.1*	*26.5*	*29.0*	*30.0*	*33.0*	*29.5*	*32.0*	*32.0*	*29.0*	*27.0*	*25.0*	*23.5*	*23.5*	
Con-10	*22.0*	*29.5*	*31.0*	*35.5*	*37.0*	*35.0*	*35.5*	*35.0*	----	----	---	----	----	----	
Con-20	*23.1*	*25.9*	*28.0*	*31.5*	*30.5*	*35.1*	*34.0*	*35.0*	*30.5*	*27.0*	*25.0*	*23.0*	*22.0*	*21.0*	
Con-25	*23.2*	*25.1*	*26.9*	*29.9*	*32.5*	*33.0*	*33.5*	*34.2*	*31.0*	*28.0*	*25.5*	*23.3*	*22.3*	*21.0*	

Table C-12: Concentrated brine temperature for the date 12-05-2006

Hour / Temp. (°C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*26.0*	*26.5*	------	*29.75*	*29.0*	*29.5*	*31.5*	*34.0*	*33.0*	*30.5*	*28.0*	*20.0*	*24.0*	*21.0*	
Con-10	------	-----	-----	------	------	------	-------	-----	-----	-----	-----	-----	-----	-----	
Con-20	*20.5*	*23.5*	------	*29.75*	*33.5*	*33.3*	*31.5*	*30.5*	*29.0*	*27.0*	*25.0*	*23.0*	*22.0*	*21.0*	
Con-25	*20.5*	*22.0*	------	*27.5*	*31.0*	*32.0*	*30.0*	*30.0*	*29.0*	*26.5*	*25.0*	*23.0*	*22.0*	*20.75*	

Table C-13: Concentrated brine temperature for the date 13-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*21.0*	*24.9*	*26.0*	*26.1*	*30.3*	*31.0*	------	------	*25.0*	*27.8*	*25.5*	*20.0*			
Con-10	-------	-------	-------	-----	-------	-------	-------	-----	------	-------	-------	------			
Con-20	*21.0*	*22.0*	*28.0*	*32.0*	*36.0*	*38.0*	------	------	*32.0*	*29.1*	*27.5*	*26.3*			
Con-25	*21.0*	*22.1*	*25.1*	*29.0*	*33.0*	*35.0*	-------	-----	*31.5*	*29.0*	*28.1*	*27.1*			

Table C-14: Concentrated brine temperature for the date 14-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23.0*	*27.0*	*30.0*	*29.0*	*32.0*	*33.0*	*31.0*	*29.0*	*33.0*	*33.0*	*27.0*	*25.0*	*23.0*	*22.0*	
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	*22.5*	*22.5*	*29.0*	*32.0*	*35.5*	*38.0*	*42.0*	*42.0*	*44.0*	*42.5*	*36.0*	*33.5*	*33.5*	*33.0*	
Con-25	*22.0*	*24.5*	*27.5*	*30.0*	*32.5*	*36.0*	*36.5*	*35.0*	*35.1*	*34.5*	*31.5*	*30.0*	*26.5*	*26.0*	

Table C-15: Concentrated brine temperature for the date 15-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*22.5*	*22.0*	*26.0*	*29.0*	*31.5*	*32.0*	*35.0*	*33.0*	*32.5*	*31.0*	*29.5*	*22.0*	*25.0*	*33.0*	
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	*24.0*	*26.5*	*31.0*	*34.0*	*38.0*	*43.0*	*45.0*	*47.3*	*44.5*	*44.0*	*37.0*	*33.0*	*27.0*	*26.0*	
Con-25	*23.5*	*25.0*	*28.75*	*31.5*	*35.5*	*37.5*	*36.5*	*37.0*	*36.0*	*34.5*	*31.2*	*29.0*	*29.2*	*28.5*	

Table C-16: Concentrated brine temperature for the date 16-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23.5*	*25.0*	*28.0*	*31.5*	*33.0*	*32.7*	*28.5*	*25.5*	*31.5*	*29.0*	*26.0*	*23.0*	*22.4*		
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	*24.0*	*26.0*	*29.5*	*34.5*	*37.5*	*39.3*	*38.9*	*31.0*	*34.0*	*33.0*	*29.0*	*24.3*	*24.1*		
Con-25	*23.5*	*25.0*	*27.0*	*31.0*	*35.0*	*36.3*	*36.8*	*34.0*	*33.5*	*32.9*	*29.5*	*26.5*	*25.3*		

Table C-17: Concentrated brine temperature for the date 17-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*230*	*27.5*	*25.0*	*30.5*	*30.3*	*33.0*	*32.0*	*34.0*	*31.0*	*30.0*	*25.0*	*25.0*	*24.8*		
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	*21.5*	*24.0*	*28.0*	*33.0*	*37.0*	*41.0*	*41.1*	*44.0*	*40.0*	*35.5*	*31.5*	*29.9*	*26.5*		
Con-25	*22.3*	*24.0*	*27.2*	*31.0*	*32.5*	*40.5*	*39.5*	*42.0*	*39.1*	*37.0*	*34.1*	*31.5*	*29.9*		

Table C-18: Concentrated brine temperature for the date 18-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.5*	*25.1*	*28.0*	*30.5*	*31.0*	*32.1*	*33.0*	*33.0*	*32.5*	*30.0*	*28.5*	*24.0*	*23.0*	*21.0*	
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	*24.0*	*26.7*	*30.0*	*34.0*	*34.1*	*24.5*	*33.0*	*30.0*	*28.0*	*25.0*	*24.0*	*23.0*	*22.0*	*21.0*	
Con-25	*25.1*	*26.1*	*28.9*	*32.5*	*33.9*	*36.5*	*38.5*	*37.0*	*35.3*	*32.3*	*29.0*	*27.0*	*26.0*	*24.0*	

Table C-19: Concentrated brine temperature for the date 19-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*22.9*	*28.0*	*32.2*	*32.5*	*31.5*	*33.5*	*34.0*	*34.2*	*29.5*	*30.0*	*28.5*	*23.1*	*23.0*		
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	*22.0*	*24.9*	*229.0*	*33.5*	*36.0*	*37.1*	*35.5*	*35.0*	--	--	--	--	--		
Con-25	*23.0*	*25.1*	*28.1*	*32.0*	*35.1*	*39.5*	*38.0*	*39.0*	*34.0*	*30.1*	*30.0*	*27.6*	*25.6*		

Table C-20: Concentrated brine temperature for the date 20-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*23*	*25*	*27.5*	*27*	*30.0*	*33.5*	*31.0*	*32.0*	*31.0*	*30.5*	*30.3*	*25.8*	*24.5*		
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-25	*22.0*	*24.5*	*27.0*	*29.2*	*33.0*	*35.5*	*34.2*	*35.0*	*33.0*	*28.0*	*26.5*	*25.2*	*22.5*		

Table C-21: Concentrated brine temperature for the date 21-05-2006

Hour / Temp. (^{O}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*26*	*28*	*28.2*	*30.0*	*30.5*	*29.5*	*33.0*	*30.0*	*32.0*	*27.5*	*25.0*	*24.3*	*24.0*		
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-25	*22*	*25.0*	*29.0*	*31.2*	*34.75*	*33.0*	*34.5*	*32.5*	*31.1*	*28.1*	*27.0*	*24.8*	*24.1*		

Table C-22: Concentrated brine temperature for the date 22-05-2006

Hour / Temp. (^{o}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*25.0*	*27.0*	*27.0*	*28.5*	*31.5*	*33.0*	*33.1*	*35.0*	*31.0*	*27.0*	*24.1*	*23.5*	*23.3*		
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-25	*23.0*	*24.5*	*26.75*	*32.0*	*35.0*	*37.75*	*38.0*	*38.1*	*34.0*	*29.9*	*29.5*	*26.1*	*25.0*		

Table C-23: Concentrated brine temperature for the date 23-05-2006

Hour / Temp. (^{o}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.2*	*23.9*	*24.9*	*29.5*	*30.5*	*29.9*	*32.5*	*29.0*	--	*24.0*	*22.5*				
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-25	*24.0*	*24.2*	*24.5*	*29.1*	*34.1*	*36.0*	*37.0*	*40.0*	--	*32.0*	*29.75*				

Table C-24: Concentrated brine temperature for the date 24-05-2006

Hour / Temp. (^{o}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.0*	*23.0*	*27.0*	*27.0*	*31.0*	*29.2*	*29.5*	*30.2*	*30.3*	*29.0*	*25.0*	*23.0*	*23.0*	*22.0*	
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-25	*23.0*	*24.0*	*28.0*	*29.0*	*32.0*	*34.0*	*34.0*	*30.2*	*30.2*	*27.75*	*24.75*	*23.0*	*22.0*	*21.0*	

Table C-25: Concentrated brine temperature for the date 25-05-2006

Hour / Temp. (^{o}C)	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	Remark
Amb.Temp	*24.0*	*27.0*	*28.0*	*28.5*	*31.0*	*32.0*	*31.5*	*35.5*	*32.0*	*30.5*	*25.5*	*23.0*	*21.0*	*20.5*	
Con-10	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-20	------	------	-----	------	------	------	-----	------	------	------	-----	------	-----	------	
Con-25	*20.2*	*22.0*	*27.0*	*32.0*	*36.0*	*37.0*	*38.5*	*37.0*	*34.75*	*31.0*	*25.5*	*24.0*	*33.5*	*23.0*	

Annex D: Concentrated brine depth

Table D-1: Concentrated brine depth for the date 01-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Con-10	*9.0*	8.7	*8.5*	*8.0*		
Con-20	*19.0*	18.7	*18.5*	*18.1*		
Con-25	*24.0*	23.8	*23.8*	*23.1*		

Table D-2: Concentrated brine depth for the date 02-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Con-10	*8.0*	8	*7.4*	*7.3*		
Con-20	*18.1*	18.1	*17.6*	*17.5*		
Con-25	*23.1*	23.1	*22.6*	*22.5*		

Table D-3: Concentrated brine depth for the date 03-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Con-10	*7.3*		*6.8*	*6.8*		
Con-20	*17.5*		*17*	*17.0*		
Con-25	*22.5*		*22.2*	*22.1*		

Table D-4: Concentrated brine depth for the date 04-05-2006

Hour / Depth	8:00	12:00	15:00	18:00	21:00	Remark
Con-10	*6.8*			*6.1*		
Con-20	*17.0*			*16.2*		
Con-25	*22.1*			*21.3*		

Table D-5: Concentrated brine depth for the date 05-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	*6.1*	*6.0*	*5.9*	*5.4*	*5.6*	
Con-20	*16.2*	*16.0*	*16.0*	*15.6*	*15.6*	
Con-25	*21.3*	*21.1*	*20.9*	*20.4*	*20.8*	

Table D-6: Concentrated brine depth for the date 06-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	*5.6*	------	*5.4*	*5.3*	*5.3*	
Con-20	*15.6*	-------	*15.4*	*15.3*	*15.3*	
Con-25	*20.8*	-------	*20.2*	*20.1*	*20.5*	

Table D-7: Concentrated brine depth for the date 07-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	*5.3*	*5.2*	*4.8*	*4.7*	*4.7*	
Con-20	*15.3*	*13.3*	*15.1*	*14.9*	*14.8*	
Con-25	*20.5*	*20.4*	*20.3*	*20.0*	*20.0*	

Table D-8: Concentrated brine depth for the date 08-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	*4.7*	*4.7*	*4.3*	*4.1*	*4.1*	
Con-20	*14.8*	*14.7*	*14.4*	*14.0*	*14.0*	
Con-25	*20.0*	*19.7*	*19.3*	*19.1*	*19.1*	

Table D-9: Concentrated brine depth for the date 09-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	*4.1*	*4.0*	*3.95*	*3.6*	*3.6*	
Con-20	*14.0*	*13.8*	*13.6*	*13.4*	*13.1*	
Con-25	*19.1*	*18.8*	*18.8*	*18.7*	*18.2*	

Table D-10: Concentrated brine depth for the date 10-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	*3.6*	*3.5*	*3.2*	*3.2*	*3.1*	
Con-20	*13.1*	*13.0*	*12.8*	*12.7*	*12.5*	
Con-25	*18.2*	*18.0*	*17.9*	*17.9*	*17.7*	

Table D-11: Concentrated brine depth for the date 11-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	*3.1*	*3.1*	*2.9*	----	-----	
Con-20	*12.5*	*12.4*	*12.4*	*12.0*	*11.7*	
Con-25	*17.7*	*17.6*	*17.5*	*17.0*	*16.8*	

Table D-12: Concentrated brine depth for the date 12-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	-------	-------	-------	-------	-------	
Con-20	*11.7*	*11.6*	*11.3*	*11.0*	*10.9*	
Con-25	*16.8*	*16.8*	*16.4*	*16.0*	*15.9*	

Table D-13: Concentrated brine depth for the date 13-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	-------	-------	-------	-------	-------	
Con-20	*10.9*	*10.7*	--	*10.5*	*10.2*	
Con-25	*15.9*	*15.7*	--	*15.4*	*15.1*	

Table D-14: Concentrated brine depth for the date 14-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	*10.2*	*10.0*	*10.0*	*9.9*	*9.8*	
Con-25	*15.1*	*15.0*	*15.0*	*14.9*	*14.7*	

Table D-15: Concentrated brine depth for the date 15-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	*9.8*	*9.6*	*9.6*	*9.3*	*9.3*	
Con-25	*14.7*	*14.6*	*14.3*	*14.2*	*14.0*	

Table D-16: Concentrated brine depth for the date 16-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	*9.3*	*9.1*	*9.0*	*8.9*	*8.8*	
Con-25	*14.0*	*13.9*	*13.8*	*13.6*	*13.6*	

Table D-17: Concentrated brine depth for the date 17-05-2006

Depth \ Hour	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	*8.8*	*8.6*	*8.5*	*8.4*	*8.2*	
Con-25	*13.6*	*13.5*	*13.3*	*13.2*	*12.9*	

Table D-18: Concentrated brine depth for the date 18-05-2006

Depth \ Hour	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	*8.2*	*8.1*	*7.7*	*7.5*	*7.4*	
Con-25	*12.9*	*12.7*	*12.6*	*12.2*	*12.1*	

Table D-19: Concentrated brine depth for the date 19-05-2006

Depth \ Hour	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	*7.4*	*7.3*	*7.0*	--	--	
Con-25	*12.1*	*12.0*	*11.9*	*11.7*	*11.5*	

Table D-20: Concentrated brine depth for the date 20-05-2006

Depth \ Hour	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	--	--	--	--	--	
Con-25	*11.5*	*11.3*	*11.2*	*11.1*	*10.8*	

Table D-21: Concentrated brine depth for the date 21-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	--	--	--	--	--	
Con-25	*10.8*	*10.7*	*10.5*	*10.4*	*10.2*	

Table D-22: Concentrated brine depth for the date 22-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	--	--	--	--	--	
Con-25	*10.2*	*10.2*	*9.8*	*9.8*	*9.7*	

Table D-23: Concentrated brine depth for the date 23-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	--	--	--	--	--	
Con-25	*9.7*	*9.5*	*9.5*	*9.4*	*9.4*	

Table D-24: Concentrated brine depth for the date 24-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	--	--	--	--	--	
Con-25	*9.4*	*9.2*	*9.0*	*8.9*	*8.8*	

Table D-25: Concentrated brine depth for the date 25-05-2006

Hour / Depth	9:00	12:00	15:00	18:00	21:00	Remark
Con-10	--	--	--	--	--	
Con-20	--	--	--	--	--	
Con-25	*8.8*	*8.7*	*8.5*	*8.3*	-------	

No	Appendix A: Sunshine hours from the Ethiopian Metrology Service Agency for the last three years and the average			
	2003	**2004**	**2005**	**Average**
1	9.8	4.7	4.7	6.4
2	4.3	5.5	10.5	6.77
3	7.9	11.0	10.5	9.8
4	3.2	5.0	11.0	6.4
5	2.5	10.3	10.2	7.67
6	10	10.4	10.0	10.13
7	3.9	10.8	10.0	8.23
8	8.8	11.3	11.0	10.37
9	2.3	11.2	10.0	7.83
10	8.1	11.4	11.0	10.17
11	8.6	9.8	8.5	8.97
12	8.2	10.9	11.0	10.03
13	8.6	11.0	10.5	10.03
14	7.5	10.5	9.0	9.0
15	9.2	10.9	10.5	10.2
16	10.0	10.2	7.5	9.23
17	9.2	11.0	10.0	10.07
18	9.0	11.0	9.5	9.83
19	6.2	10.7	10.5	9.13
20	3.9	11.0	10.5	8.47
21	2.3	10.2	11.0	7.83
22	9.4	8.8	11.0	9.73
23	9.2	10.1	10.0	9.77
24	9.1	8.3	7.0	8.13
25	8.4	9.2	10.0	9.2
26	8.4	9.7	11.0	9.7
27	4.3	10.8	11.0	8.7
28	5.9	9.4	11.0	8.77
29	10.5	9.9	11.0	10.47
30	10.3	9.6	10.5	10.13
31	11.4	10.7	11.0	11.03

No	Appendix B: Wind speed in m/s from the Ethiopian Metrology Service Agency for the last three years and the average			
	2003	2004	2005	Average
1	1.55	2	2.97	2.17
2	1.42	1.57	2.6	1.86
3	1.23	1.82	1.15	1.4
4	2.07	1.76	0.96	1.6
5	1.69	1.55	1.13	1.47
6	0.8	1.79	1.63	1.41
7	1.05	1.39	1.46	1.3
8	1.89	1.75	1.3	1.65
9	0.98	1.16	1.35	1.16
10	0.86	1.55	2.34	1.58
11	1.26	2.22	1.8	1.76
12	1.25	1.65	1.15	1.35
13	2.12	1.85	1.27	1.75
14	1.21	1.82	1.43	1.49
15	1.71	2.53	2.51	2.25
16	1.18	2.19	1.6	1.66
17	1.33	1.99	2.47	1.93
18	1.42	2	1.99	1.8
19	1.1	1.83	2.06	1.66
20	1.28	1.72	1.88	1.63
21	0.64	1.2	2.37	1.4
22	0.64	2.32	1.85	1.6
23	1.88	2.98	2.35	2.4
24	2.44	2.65	2.18	2.42
25	1.53	2.41	2.2	2.05
26	1.57	2.44	2.21	2.07
27	1.2	2.78	2.43	2.14
28	0.99	2.66	1.44	1.7
29	1.47	2.7	1.18	1.78
30	1.2	2.96	2.14	2.1
31	1.02	2.79	2.31	2.04

Declaration

This Thesis is My Original Work, Has Not Been Presented for a Degree in any other University that all Source Material Used for the Thesis are duly acknowledged.

Sileshi Kore

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Signature

This thesis has been submitted for the examination with my approval as a university advisor.

Advisor:
Dr.-Ing Abebayehu Assefa

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Signature