Chapter 7
Evaporation Ponds

Abstract Evaporation ponds are a low technology solution for concentration management whereby brine is pumped into large ponds and water slowly evaporates via direct solar energy. They are a widely used method of saline water management in the Middle East and Australia. The simplicity of the process reduces maintenance and operating costs, and greatly reduces energy requirements. Leakage from evaporation ponds can cause contamination of surrounding land and water sources, so the prevention of leakage through adequate design is crucial. Evaporation ponds should not be confused with solar gradient ponds, which use concentrated brine to produce electricity.

Keywords Costs · Environmental concerns · Evaporation pond design · Evaporation rate · Liners · Pond area · Pond banks · Pond depth · Social impacts

7.1 Design

The design of an evaporation pond must take into account both the volume of concentrate from the plant and the evaporation rate at the selected site. The prevention of salinity in surrounding areas and the contamination of nearby potable aquifers is of great importance and must be carefully considered during the design phase. The major design factors to consider are the pond area, depth, liners and bank size.

7.1.1 Pond Area

The required surface area of a pond is dependent upon both the volume of concentrate and the evaporation rate. Surface area, A (m^2), can be estimated using the following equation:

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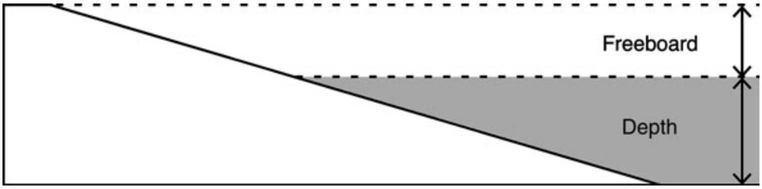

Fig. 7.1 Cross sectional view of the inner bank of an evaporation pond showing depth and freeboard

$$A = \frac{V}{E} \tag{7.1}$$

where V is the volume of concentrate sent to the pond (m^3/day) and E is the evaporation rate (m/day). A greater volume of concentrate will increase the required pond area, and a higher evaporation rate will reduce the required area. Laser leveling can be used to ensure a more even evaporation rate across the pond, and hence a smaller required area (Ahmed et al. 2000). A safety factor should also be applied to the calculated pond size for the event of a lower than anticipated evaporation rate, or unexpected increases in concentrate volume. It is recommended that a 20% safety factor be applied to surface area of the pond (Mickley 2006).

7.1.2 Pond Depth

The minimum depth of a pond is directly proportionate to the rate of evaporation. This depth needs to allow for increases in volume, the precipitation of salts, as well as for rainfall and waves. It is estimated that the best evaporation rate can be achieved with pond depths of 0.03–0.45 m, however ponds with depths of up to 1.02 m have been shown to have reasonable evaporation rates (Mickley 2006). Similarly to pond area, a safety factor can be applied to the calculated minimum pond depth to increase the capacity and prevent the pond from overflowing. This extra depth will depend upon the expected additional discharge volume at the beginning of plant operation (Mickley 2006), and the ambient conditions during winter, at which time the pond may store water rather than reduce its volume (Ahmed et al. 2000).

The freeboard of an evaporation pond is the height between the design depth and the top of the bank, as shown in Fig. 7.1. Freeboard accounts for wave action due to wind, volume increases when the evaporation rate is lower than expected, surges and rainfall. Ahmed et al. recommend that the freeboard height be 0.2 m (Ahmed et al. 2000), however recommendations for evaporation basins on the Riverine Plain in Australia suggest freeboard should be 0.6–0.8 m (Leaney and Christen 2000). Ultimately, the freeboard height should be determined based on the specific climatic conditions at the site of the pond, including the average rainfall and anticipated wave height. The following equation may be used to estimate the height of pond wave action (Mickley 2006):

$$H = 0.007W\sqrt{F} \tag{7.2}$$

where H is the wave height (m), W is the wind velocity (km/h) and F is the fetch, the straight line distance wind can blow without obstruction (km). Note that wave height can be minimised by constructing the pond with its length perpendicular to the prevailing wind direction (Ahmed et al. 2000).

7.1.3 Evaporation Rate

While the volume of concentrate can be determined based on plant capacity and recovery, the evaporation rate at any given site varies with climate. To determine the evaporation rate of fresh water at certain locations, a standard pan evaporation measurement is taken. Evaporation pans are small, open air pans filled with water from which losses in water due to evaporation are measured. Standard size Class A evaporation pans are most commonly used, which are 1.207 m in diameter and 0.25 m in depth. The daily change in depth, minus any rainfall, is used to determine the evaporation rate in mm/day. This rate takes into account the effects of climate on evaporation rate, but corrections for pond area and salinity must be made when determining the evaporation rate of a specific evaporation pond.

The humidity gradient between the water in the pond and the water in the air above the pond is the driving force for the evaporation process. Larger ponds have a different environment and greater humidity above the water, reducing this driving force and hence the evaporation rate (Leaney and Christen 2000; Morton 1986). The evaporation factor, F_1, is a correction factor that adjusts the pan evaporation rate based on pond size. It can be approximated by (Jolly et al. 2000):

$$F_1 = 1 - 0.029\ln(A) \tag{7.3}$$

where A is the pond area (ha). This relationship can be seen in Fig. 7.2. As the pond size approaches the size of the evaporation pan, the evaporation rate approaches that of the pan.

Evaporation rate is also affected by the salinity of the water. Saline water has a lower evaporation rate than fresh water, as salt reduces the vapour pressure of the water, decreasing the driving force for evaporation. A second evaporation factor, F_2, the evaporation rate of saline water compared to fresh water, can be approximated as (Leaney and Christen 2000):

$$F_2 = 1.025 - 0.0245e^{0.008795} \tag{7.4}$$

where S is the salinity of the solution (g/L) up to 320 g/L. This relationship is shown in Fig. 7.3. It can be shown from this equation that the evaporation rate will

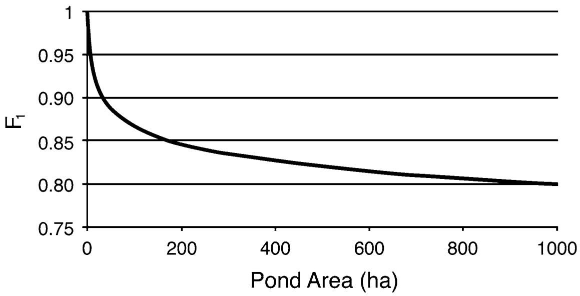

Fig. 7.2 Decreasing evaporation rate due to the oasis effect as pond size increases. Adapted from Jolly et al. (2000)

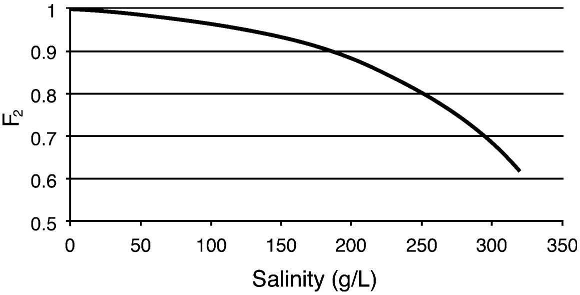

Fig. 7.3 Decreasing evaporation rate of salt water compared with fresh water as salinity increases. Adapted from (Leaney and Christen 2000)

slow with time as water is evaporated and the salinity of the pond increases. Note that when determining the evaporation rate for a pond, this relationship should be used as an estimation only, as the exact relationship between salinity and evaporation rate relies on a great number of site specific factors other than salinity, including air temperature, wind velocity, relative humidity, barometric pressure, water surface temperature, heat exchange rate with the atmosphere, incident solar absorption and reflection, pond thermal currents and pond depth (Mickley 2006).

When determining the evaporation rate for an evaporation pond in the absence of a corrected pan evaporation rate, an approximation of 70% of the freshwater evaporation rate is considered reasonable (Mickley 2006).

7.1.4 Pond Liners

Pond liners are used to prevent the leakage of concentrate, which can cause soil and groundwater contamination. They are geomembranes fabricated from materials such as high-density polyethylene, low-density polyethylene, polyvinyl chloride or polypropylene. They should be strong enough to withstand cleaning without causing leaks, and the pond needs to be deep enough to prevent the liner from drying and cracking (Mickley 2006). The requirement for liners is a major drawback for evaporation ponds, as they are usually the largest cost (Nicot et al. 2009).

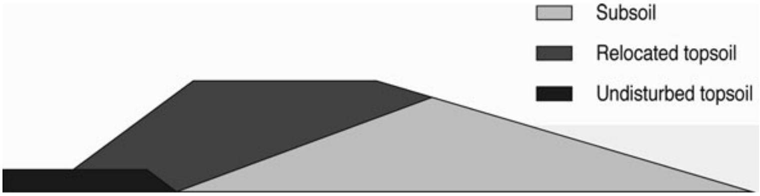

Fig. 7.4 Cross-sectional view of a bank showing a soil pattern to minimise erosion and encourage vegetation growth on the outer slope. Adapted from (Singh and Christen 2000)

The sealing of liner joints upon installation is very important, as this is where leaks are likely to occur (Glater and Cohen 2003). Several research efforts have investigated the possibility of ‘self-sealing’ evaporation ponds for concentrate disposal in Texas (Nicot et al. 2009; Turner et al. 1999). Self-sealing liners are created by adding chemicals to the concentrate that reduce the porosity and permeability of the existing liner or soil. Nicot et al. (2009) produced a report outlining possible approaches for self-sealing liners. Self-sealing liners have the potential to reduce costs by waiving regulations that stipulate the required thickness of liners and the groundwater monitoring systems. A reduction in liner thickness or ponds with no liners would significantly reduce the capital cost of a pond. Unfortunately, no practical self-sealing solution currently exists, and further work is required to reduce costs and produce a solution that is technically and economically viable.

Evaporation ponds or disposal basins are widely used in the Murray-Darling Basin in Australia to reduce salinity in irrigation areas. These basins are similar to evaporation ponds for concentrate disposal, but they may be designed to have a controlled amount of leakage. This eliminates the need for liners, but additional costly earthwork must be done to compact the soil and reduce its permeability, and additional leakage interception processes must be installed. Nonetheless, if a controlled amount of leakage is acceptable, this option is often cheaper than the use of a liner (Singh and Christen 2000). Specific guidelines for the construction and use of evaporation ponds for irrigation water can be found elsewhere (Jolly et al. 2000; Singh and Christen 2000; Christen et al. 1999).

7.1.5 Pond Banks

The banks around evaporation ponds can be built from the existing soil and excavated earth. It is suggested that a layer the topsoil be removed from the pond area, and the subsoil underneath be used to form the inside of the bank. The outer slope of the bank can be covered in the removed topsoil, as this promotes the regrowth of vegetation (Singh and Christen 2000). An example of this is shown in Fig. 7.4.

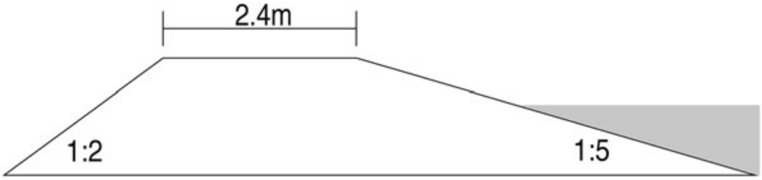

Fig. 7.5 Cross-sectional view of a bank showing suggested dimensions. Adapted from (Singh and Christen 2000)

Suggested dimensions for evaporation ponds are given by Singh and Christen (2000), and these can be seen in Fig. 7.5. The banks surrounding the pond should be a minimum of 1 m high and 2.4 m wide to allow for vehicular access. To reduce erosion, it is recommended that the slope of the inner bank should be 1:5 and the outside bank a slope of 1:2.

7.2 Pond Costs

The feasibility of an evaporation pond is determined by the volume of concentrate, the cost of land and the ambient evaporation rate. They are most cost-effective in areas with low rainfall, high evaporation rates, and where large expanses of land are available at low cost (Mickley 2009). This best suits inland desalination plants in regional and remote areas where these conditions can be met.

Evaporation ponds have a poor economy of scale and while they are economic for small waste flows, the largest feasible volume of concentrate is typically no greater than 5 MGD (Glater and Cohen 2003). Moreover, if the evaporation rate is low during the cooler months, the pond area may increase to an unfeasible size. In such instances, alternative disposal methods or concentrate storage options should be considered (Mickley 2009).

The major cost factors of an evaporation pond include pond liners, land preparation, excavation and clearing, site surveying, bank construction, pumps, control systems, disposal of precipitated solids, maintenance and geotechnical investigation of the site (Singh and Christen 2000). Of these, pond liners typically represent the greatest cost (Nicot et al. 2009).

Typical maintenance costs for an evaporation pond are pump maintenance and replacement, erosion control (including the replacement of eroded banks), vegetation management, wildlife control and seepage control. Bank rebuilding can include up to 10% of the banks every 10 years (Singh and Christen 2000). Annual operating costs are generally very low, and can be approximated at 0.5% of the total installation cost (Mickley 2006). The cost of the bank surrounding the pond increases with height, but so too does the storage capacity per unit area. A suitable balance must be found that allows enough freeboard and additional storage capacity while keeping construction costs to a minimum. Approximate bank, liner, fence and road costs based on pond size can be found elsewhere (Mickley 2006).

The disposal of solids is generally not required but may be necessary if the amount of precipitated solids becomes too great, if there is a high amount of suspended solids or dirt, or if the pond is too shallow (Mickley 2006). Salt disposal includes disposal to sea, landfill or other designated waste disposal sites, and this can become a costly process.

7.3 Environmental Concerns

The leakage of concentrate and potential contamination of the surrounding environment and aquifers with salt and other chemicals is the largest threat posed to the environment by evaporation ponds. There is also potential for the high salinity water to impact local wildlife and for salt spray to harm surrounding flora (Mickley 2009; Schliephake et al. 2005).

The contamination of groundwater can negate any existing use that water may have, or prevent its future use. Furthermore, if not prevented and controlled, salinisation can affect nearby crops, pastures, infrastructure and buildings. The impacts of salinity have been widely studied and will not be discussed here.

A number of measures can but put in place to monitor for leaks and help prevent the contamination of groundwater. These can also reduce the potential buildup in soil and groundwater of heavy metals which may be present in the concentrate, and which can lead to long-term problems (Mohamed et al. 2005). Monitoring wells can be installed to observe the water quality in nearby aquifers, and any changes in these may indicate a leak. When ponds have two liners (as may be required based on the extent of nearby aquifers and local regulations), any leakage that makes its way through the first liner may be detected via a connected monitoring sump, or through a moisture detector inserted between the two liners (Mickley 2006).

In some areas it may be acceptable for a small amount of leakage to occur from a pond, however this is more applicable for evaporation ponds used for irrigation water control rather than concentrate disposal. In such cases, the salt not contained by the pond should be contained in the soil and aquifer system directly below and adjacent to the pond (Christen et al. 1999). This ensures a large amount of the salt can eventually be recycled back into the evaporation ponds through appropriate interception methods. As stated above, leakage should not contaminate any groundwater with existing or potential use, and should minimise any potential environmental damage. The decision to allow leakage needs to be done on a case by case basis after an appropriate geological assessment.

To reduce the environmental impact of an evaporation pond, the environmental sensitivity, hydrogeology and land characteristics of the site should be assessed during site selection. In particular, the proximity of the site to conservational areas, flood plains, wetlands, swamps and residential and commercial areas needs to be assessed (Singh and Christen 2000). Once a site has been selected, detailed on-site hydrogeology assessment can be performed when required, including the depth, extent, piezometric level, transmissivity and water quality of any nearby aquifers (Singh and Christen 2000).

7.4 Social Impacts

Evaporation ponds are often viewed negatively, particularly due to potential salinisation of local land, unpleasant odours and aesthetic problems (Christen et al. 1999). The siting and design of an evaporation pond must then take these factors into account. The planting of trees around the perimeter of a disposal basin has been suggested as a way to increase social acceptance. The pond site should also include a buffer zone to position the pond an appropriate distance away from residential and commercial areas, schools, hospitals and other public areas (Jolly et al. 2000; Christen et al. 1999).

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