# Global Hyper Saline Power Generation Qattara Depression Potentials

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# Maher Kelada

MIK Technology 2100 West Loop South, Suite 900 Houston, Texas, USA 77027 Maher.Kelada@miktechnology.com

Abstract- This article is a synopsis of the past and current technology development schemes created to propose the potential of generating power by the physical phenomenon of osmosis. In addition, it offers a new concept in exploring the potential of the Qattara Depression of Egypt and the like, not only for generating power, but also for creating vibrant living communities from these desolate lands.

# I. Introduction

Osmosis is nature's gift to life. It is the vehicle that transports fluids in all living cells and without it, all biological functions and all forms of life cease to exist! Osmosis is the spontaneous movement of water, through a semi- permeable membrane that is permeable to water but impermeable to solute. Water moves from a solution in which solute is less concentrated to a solution in which solute is more concentrated.

The driving force of the flow movement is the difference in the chemical potential on the two sides of the semi-permeable membrane, with the solvent moving from a region of higher potential (generally of a lower solute concentration) to the region of lower potential (generally of a higher solute concentration).

The term "Chemical Potential" at times can be ambiguous and elusive. In fact, it is one of the most important partial molal quantities. It is the energy source associated with the activity of the ions of an ionizable substance. It is equal to the rate of change in free energy of a system containing a number of moles of such substance.

Chemical potential can be viewed as another form of energy like electrical, gravitational, momentum, magnetic, surface tension, etc. Thermodynamically, this energy is expressed in terms of what is conventionally known as Gibbs free energy.

To prevent water permeation across the semipermeable membrane, a pressure has to be imposed against the permeated flow to equalize the force created by the chemical potential difference across that membrane. This force is named osmotic pressure. If the imposed pressure exceeds this limit, then water begins to flow from the region of higher solute concentration to the region of lower solute concentration. In this case, the force is named reverse osmosis pressure.

## A. Osmosis Thermodynamics

Thermodynamically, the internal energy generalized differential form is given as:

$$dU = TdS - pdV + \mu dN + \varphi dQ + v dp + \psi dm + \ell dA \dots (1)$$

Where, entropy *S*, volume *V*, amount of substance *N*, electric power *Q*, momentum p, mass m, area *A*, etc. are extensive quantities and temperature *T*, pressure *p*, chemical potential  $\mu$ , electrical potential  $\varphi$ , velocity v, gravitational potential  $\psi$ , surface tension l, etc. are energy-conjugated intensive quantities.

The combined first and second laws of thermodynamics can be reduced in terms of Gibbs free energy to give:

$$dG = Vdp - SdT + \Sigma_i \,\mu_i \,dN_i \tag{2}$$

This relation is further reduced to give a simple mathematical relation in terms of osmotic pressure  $\pi$ , concentration and temperature. Osmotic pressure was originally proposed by Nobel Laureate Van't Hoff and modified to include Staverman's osmotic reflection coefficient to become:

$$\pi = \Phi I C R T \tag{3}$$

Where:

 $\pi$  = osmotic pressure or force imposed on the membrane given in bars, atm, psi, etc.

 $\Phi$  = Osmotic Reflection Coefficient (NaCl = 0.93, CaCl<sub>2</sub> = 0.86, MgCl<sub>2</sub>= 0.89, etc.), It is ratio of real to ideal osmotic pressures for a given membrane, I = Ions concentration per dissociated solute molecule (Na<sup>+</sup> and Cl<sup>-</sup> ions = 2),C = molar concentration of the salt ions, R = gas constant (0.08314472 liter · bar / (k.mol)),T = ambient temperature in absolute Kelvin degrees.

The average concentration of salt in oceans around the globe is about 3.5% (35 gram/liter), mostly in the form of sodium chloride (NaCl). For simplicity of calculation, it is assumed that seawater contains 35 grams NaCl/liter. The atomic weight of sodium is 23 grams, and of chlorine is 35.5 grams, so the molecular weight of NaCl is 58.5 grams. Therefore, the number of NaCl moles in seawater is 35 / 58.5 = 0.598mol / liter and the osmotic pressure of seawater is:

 $\pi = [0.93]$  [2] [0.598 mol/liter] [0.08314 liter. bar/ (k.mol)] [293 K] = 27.1 bar

## **B.** Osmotic Power Systems

The osmosis process for salinity power generation is rather simple and requires a few basic units of operation; semi-permeable membrane modules ( $\mathfrak{M}$ ), solution pumping means (P) and turbine ( $\mathfrak{T}$ ) generator to recover osmotically generated energy.

Considering a freshwater-seawater osmotic scenario as an example, if the seawater with 3.5% salt content is pumped at a rate of  $1m^3/s$  (one cubic meter/second) on one side of a membrane and simultaneously freshwater on the other side of the membrane is permeated across the membrane with the same flow, then the flow leaving the seawater side is at a rate of 2 m<sup>3</sup>/s, but now at half of the original concentration or 1.75 percent.

It should also be clear that the seawater pumping pressure in the system is equivalent to the osmotic pressure of the diluted seawater at the point of discharge from the membrane that will then enter the turbine. In another words, the seawater pump delivery must have a pressure of 196 psi (138 meter), which is equivalent to the osmotic pressure of the 1.75 percent salt concentration.

FIG. 1 illustrates two cases. Both systems operate with pump and turbine efficiencies of 75% and 85% respectively In the case of FIG. 1A, seawater (SWS, SWR) is exchanged with freshwater (FW) operates with an energy deficit [1]. In the case of FIG. 1B, reverse osmosis brine is exchanged with freshwater operating with an energy efficiency of 4%. Higher brine concentration results in higher system efficiency.



FIG. 1 Osmotic power generation equipment arrangement

## **II.** Qattara Depression Potential Energy Generation

#### A. Brief history of hydro-solar Qattara project:

The utilization of the Qattara Depression to develop hydroelectric power was first suggested by the Berlin geographer Professor Penk in 1912 and later by Dr. Ball in 1927. Dr. Ball studied in particular the possibility of utilizing the depression for hydroelectric purposes by the formation of lakes at final levels of 50 m, 60 m, and 70 m below sea level, to which the corresponding surface areas were 13,500, 12,100, and 8,600 km<sup>2</sup>. Moreover, he indicated the most convenient water inflow routes (lines D, E, and F) with reference to the formation of the lakes [2]. See also FIG. 3.

After examining the effect of climatic changes, evaporation, seepage, minor transmission losses and the lowest cost per kW installed, he showed that the most convenient solutions were those relating to lakes at 50 and 60 meters below sea level. From geological and topographical considerations, he finally recommended -50 m below sea level with route D for the supply line.

In 1950, Siemens proposed a scheme involving the creation of an artificial balancing reservoir on the edge of the depression, continuously fed by two conduits from the Mediterranean.

In 1964, professor Bassler was appointed by the West German ministry of Economics and in his 1968 articles he presented a scheme shown in FIG. 2. Unfortunately, he is the person who found dredging of a channel or the excavation of tunnels would be too expensive, so he suggested blowing up of a channel with nuclaer explosives, by driling 213 drill holes, filling each with one megaton of explosives; for reference each has fifty times the explosive effect of the atomic bomb on Hiroshima. As a conequence of this frightening opinion, the Egyptian goverment, at the time, declined its support to the project.



FIG. 2 Qattara abandoned hydro-Solar project

# B. Qattara Hydro-solar Project Aspects:

The primary objective of the final proposal was to transfer seawater to the depression by either a tunnel or by a

canal. Steady state operation is based on the rate of evaporation from the lake surface when the water level reaches 60 m below sea level. The theoretical hydro-potential at this level is estimated to be 315 MW, assuming a water surface area of 12,100 km<sup>2</sup> and evaporation of 1.41 m per year.

Referring to FIG. 2, the proposed power potential of 315 MW was estimated by assuming a maximum flow of 600  $m^3/s$ , or 51.8 million  $m^3$  per day. This process would require about 35 years for filling the lake to 60 m below sea level.

The Secondary objective was to construct an elevated storage facility to be meet peak power demand of 2,085 MW for duration of 4.5 hours daily.

The site for this elevated storage facility was located atop a mountain 188.0 m above sea level, having a volumetric capacity of 45 million m<sup>3</sup>. It was postulated that this capacity is sufficient to meet peak demand for 3 days (15.16 million m<sup>3</sup> per day) at a discharge flow rate of 936 m<sup>3</sup>/s during peak hours.

We question the validity of such concept. If  $600 \text{ m}^3/\text{s}$  generate 315 MW by dropping water 60 meter below sea level, then how much energy is required to recycle 15.16 million m<sup>3</sup> of water per day (175.5 m<sup>3</sup>/s) from 60 meter below sea level to store it at 188 meter above sea level? Unfortunately, our rigorous analysis reveals the fallacy of this power generation scheme.

#### C. Alternative Energy to Hydropower

In reference to equation (1), hydropower is a form of gravitational potential energy,  $\psi dm$ . The theoretical hydro potential energy (P<sub>th</sub>) is the force multiplied by the distance through which the object falls. This can be presented as:

$$P_{th} = \text{gravity force x height}$$
 (4)

 $P_{th}$  = density x volume flow x gravity constant x height (5)

Since earth gravitational acceleration is constant, then the primary variable to determine the gravitational energy potential of a unit of mass is the height, h. As an example, if  $\rho = \text{density} (\text{kg/m}^3) (\sim 1000 \text{ kg/m}^3 \text{ for water}), q = \text{water flow}$ (m<sup>3</sup>/s), g = acceleration of gravity (9.81 m/s<sup>2</sup>), h = falling height, head (m), then for 100 m drop each one m<sup>3</sup>/s will generate 0.981 MW, for 200 m drop, one m<sup>3</sup>/s will generate 1.962 MW, and so on.

On the other hand and in reference to equation (1), osmotic power potential is a form of chemical potential,  $\mu dN$ . It is attainable when water of dissimilar salt concentration exists and can be used to operate an osmotic power generation system. Such system can be an open or a closed system anywhere solar radiation or waste heat can be found to supply it. Estimated theoretical osmotic power potential is about 0.765 MW for every  $1\text{m}^3$ /s contains 1% sodium chloride salt. For higher salt concentration solution, power potential could be several times the hydro-solar power.

#### D. Osmotic Power Generation Development

The phenomenon of osmosis is well known for many years; however application of osmosis for power is in its

inception state. The number of patents that have been granted in the last four decades involving osmosis applications for power generation can be counted on one hand. This is due to the predominant factors that determine the validity of largescale salinity power generation system. The first factor is the availability of high osmotic potential sources in nature. The second factor is the availability of semi-permeable membranes that are capable of meeting the requirement of the new technology. The third factor is the capability of using natural water resources efficiently. These three factors are the primary hurdles to overcome in developing the potential of salinity power generation.

The most significant attempt in this field was a U.S. patent No 3,906,250 that was granted to Sidney Loeb in 1975. This patent describes a method and apparatus for generating power by utilizing "Pressure Retarded Osmosis, PRO", a terminology that was adopted by Loeb in his work. This work has both historical and conceptual value in studying salinity power.

Statkraft of Norway [3] has adopted Loeb's work in developing their osmotic power generation pilot plant that was commissioned on November 24, 2009 to produce 10 KW of power. The final assessment of that pilot plant has not been revealed, but it was stated that the system was capable of producing 2 KW of power at differential head of 120 meters, employing 2000 square meters of spiral wound membrane. Despite scarcity of test information, this data was sufficient to debate the merits of the freshwater-seawater osmosis generation scenario. Please view [4].

#### **III. MIK Technology Osmotic Power Generation**

The MIK Technology concept for power generation encompasses world endorheic (dead ended) saline and dry salt lakes as well as from high concentration of formulated ionizable inorganic salt. The subject technology targets the world' natural basins and hyper saline lacks.

Such natural basins include the Qattara Depression-Egypt, Great Salt Lake-U.S., Lake Torrens-Australia, Lake Assal- Djibouti, Lake Urmia-Iran, Lake Eyre North-Australia, Lake Baskunchak--Russia, the Dead Sea-Israel& Jordan, Lake Van-Turkey and many others.

Simplistically, osmotic power can be generated by running fresh water on one side of a semipermeable membrane and salty water along the opposite side of the membrane. Water tends to permeate spontaneously from the fresh water side causing accumulation of water in the salty water side, where this excess in water can be used to drive a power generation turbine.

FIG. 3 illustrates a simplified schematic based on MIK technology for generating osmotic power from a salt bed in Australia, known as Torrens Lake. This lake has a surface area of about 5700 square kilometers.

The process is based on transporting seawater from Spenser Gulf at Port Augusta, south of Australia in a 1000  $m^3$ /s canal to fill the lake. The concentrated brine is then used against the incoming sea water to generate power.

The potential power exceeds 2 Gigawatts in addition to a large amount of seawater minerals. The potential of this lake is much greater than what is shown. The conceptual design in this case was based on the premise that all excess and rejected streams had to be recycled to the lake. Therefore, the amount of minerals would be a controlling factor in defining the operation parameters of this system.



FIG. 3 Torrens Lake's Osmotic Power Generation

In this case, if the excess flow with 6.91% salinity was returned to the sea, the generated power could approach 3.5 Gigawatts. Therefore, MIK Technology has adopted the concept of minimizing salt accumulation in their proposed scheme for generating osmotic power from the Qattara Depression in order to maximize recovered energy [4].

#### **IV. Proposed Qattara Depression Development**

## A. The Qattara Depression Aspects

The depression is located in the north-western part of Egypt and is the world's fifth deepest natural depression. The depression is bounded to the north and west by deep escarpments but becomes comparatively flat towards the south and the east. The lowest point is found at a level of 133 meters below sea level.

The depression has a length of about 300 km at sea level, a maximum width of 145 km, and an area of 19,500 km<sup>2</sup>. The northern edge of the embankment is bounded by a hilly ridge with an elevation of about 200 m above sea level, with the shortest distance from the Mediterranean Sea of about 56 km.

As indicated earlier, the primary objective of the hydrosolar project is to generate sustainable source of energy of 315 MW, with a secondary goal to provide an elevated storage of 45 million cubic meters to manage peak power demand.

It was estimated that steady state operation will be reached in approximately 35 years. In this process, salt continues to accumulate and water reaches it salt saturation within 30 years. In essence, the project will create another dead sea that will not be capable of supporting any form of life.

In fact, it was estimated that the depression could become full of salt in several hundred years [2]. This will not only prevent any attempt for site development, but will also create economical and environmental havocs in the Nile valley due to the salt dust that would be carried with the familiar North Africa sand storms.

#### C. Osmotic Power Alternative Plan

MIK Technology alternative to the hydro-solar project is an osmotic power generation facility providing a source of sustainable energy at the equivalent power potential, and at a fraction of the water requirement.

The proposed osmotic power system requires only 60  $m^3$ /s of water to generate 360 MW of power, rather than the 656  $m^3$ /s required by the hydropower scheme to generate 315 MW. This alternative system is presented in FIG. 4. Table 1 illustrates the operating parameters of such system.

Since osmotic power requires high salinity brine, then seawater has to be concentrated by solar evaporation to reach the required salinity. Therefore, an area of low land approximately 630 km<sup>2</sup> will be required to generate the brine for this process. Regardless, such a facility will be required to provide the necessary power to construct the proposed Qattara full scale project as explained later.



FIG. 4 Alternative Energy Plan for Hydro-Solar Concept

360 MW Qattara Depression Osmotic Power Plant contender of 1975 Proposed Hydropower Project	
Energy Estimation	TOTAL
Potential energy generation (E) @85% Sum of pumping energy (PE) @75% Membrane LMCD Net energy generation (NE) System Efficiency NE/E% Required Seawater Flow m <sup>3</sup> /second Hydro-Solar flow @315 MW, m3/second	724 MJ -364 MJ 3 (Est.) 360 MJ 49.7% 60 656

Table 1 Osmotic power alternative to hydro-solar power

## D. Qattara Depression Ultimate Potentials

Qattara Depression development requires complete understanding of area topography, elevation points and parameters. The Qattara Depression Source of Raw Data was originated in the NASA Shuttle Radar Topographic Mission (SRTM) data held at the National Map Seamless Data Distribution System. Such data are presented in FIG. 5 & 6 and are used in this evaluation.







FIG. 6 Depression Sections at Different contour lines

The osmotic power concept that was described in FIG. 4 can be expanded to generate 3.0 Gigawatts from the Qattara Depression at an efficiency of 51% and  $26 \text{ MW/m}^3$  of brine. However, this article is considering a unique approach, taking into account not only the demand for benign energy, but also enhancing the country's resources in water, energy and food; as well as relieving over populated communities, and encouraging socio-economic development. Our proposed concept, as shown in FIG. 8 is based on partitioning the depression into two parts of about equal surface area. The

north section will be used to develop high salinity brine needed for osmotic power generation. The south section, which is deeper and has higher volumetric capacity, will be used as a large lake for farming marine life.

Water will be supplied from the Mediterranean Sea, preferably in a navigable canal for light rafts, for maintenance and to fill the south section of the depression. The water intake is preferably located east of the town of Al Alamein and will run along the eastern edge of the depression. The slope of the canal will be limited by water level in the receiving end of the depression, which will be kept at 20 meter below sea level. FIG. 7 indicates earlier proposals to extend water to the depression.



FIG. 7 Qattara Region Elevation Profile

It should be recognized that this project could rival the Aswan High Dam project. The proposed southern section of the depression will have a surface area of about 8,800 square kilometer, which is 70% larger than the surface area of Nasser Lake ( $5250 \text{ km}^2$ ). Its volume is expected to be 443 cubic kilometer or four (4) times the volume of Nasser Lake ( $111 \text{ km}^3$ ).



FIG. 8 The Qattara Depression Operation Proposal

To simplify referencing to this section, let us call it the "Qattara Sea", in analogy to the Aral Sea and the Dead Sea.

In order to enhance community development and economical welfare, the Qattara Sea will be used primarily for marine life and urban development around its hundreds of kilometers of shores. Therefore, it is necessary to maintain water salinity constant, implying that there would be no accumulation of salt after filling the Qattara Sea with water. Water in this newly developed sea will be maintained at 20 m below sea level

The incoming seawater flow will greatly be dependent on the adaptability of marine life to salinity greater than that of seawater (3.5%). Water flow rate is dependent on the evaporation rate, which was reported earlier by many researchers to be 1.5 meter per year. The flow rate to maintain 4% salinity is estimated at 3400 m<sup>3</sup>/s, which is 80% higher than the required rate if 4.5% salinity is maintained.

Discharged water will be used to fill the north section of the depression, which will be referred to as the Brine Lake, as well as providing the light salinity stream to operate the osmotic power generation process. The water level in the Brine Lake will be maintained at 50 meter below sea level.

The recycled water from the osmotic power generation will re-enter the Lake at about 8% salinity and leaves at 30% salinity or higher, depending on the evaporation rate. The excess flow from the process, which could vary between 1,100 and 2000 m<sup>3</sup>/s, as determined by the operating concentration of the Qattara Sea, will exit the Osmotic Power plant below sea level. Therefore it has to be pumped back to the sea, also in a canal, paralleling the intake canal.

Based on the large size canals associated with marinating 4% salt concentration in the Qattara Sea, the depression can be filled with water in only 5 years. It is also realistic to assume that such large facility as shown in FIG. 9 could be constructed, commissioned and in full operation by 2025.

#### V. Conclusion

Exploiting the potential of the Qattara Depression by employing osmotic power generation technology is a worldclass event. This will be a witness to the tenacity and endurance of the people of Egypt to reshape their presence and to build a prosperous future.

This project is capable of generating 3.0 Gigawatts of power. This electrical power can meet the demand of a population of 3-5 million households, while producing zero carbon emissions and radiation.

Maintaining the Qattara Sea salinity constant can produce varieties of marine life in thousands of tons annually that will employs thousands of people in a large scale fishing industry. Recycled high salinity brine streams can be a major source for mining seawater minerals in millions of tons annually and in the process creating new industries and thousands of jobs. Desalinated water produced by reverse osmosis powered with site generated electricity can irrigate thousands of acres as well as transform desolate lands into vibrant communities that have reliable energy and food sources.

Filling the Qattara Depression with continuously running sea water could significantly moderate the weather by about 3-5 degrees centigrade. The high rate of the evaporation can also be a beneficial factor in terms of enhancing rainfall.

The long shores of the Qattara Sea can also support major urban development and upscale resorts that could prompt migration from the Nile valley and the resettlement of foreigners and tourists.

In summary, the proposed technology will provide the necessary resources that will encourage the development and the proliferation of mid-Saharan communities [7].



FIG. 9 Proposed Qattara Depression Development

#### **VI. Referencies**

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