How are Osmotic Pressure and Power Calculated?

This post is in response to readers of my article, "Seawater Osmotic Salinity Power Reality." Without getting into many thermodynamic derivations, the combined first and second laws of thermodynamics can be reduced in terms of Gibbs free energy to:

$$dG = Vdp - SdT + \Sigma_i \mu_i \, dN_i$$

Where, entropy S, volume V and substance amount N are extensive properties and temperature T, pressure p, and chemical potential μ are energy-conjugated intensive quantities.

This relation is further reduced to give a simple mathematical relation in terms of osmotic pressure π, 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:

$$\pi = \Phi ICRT$$

Where:

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

Φ = Osmotic Reflection Coefficient (NaCl = 0.93, $CaCl^2$ = 0.86, $MgCl^2$= 0.89, etc.), [It is ratio of real to ideal osmotic pressures for a given membrane]

I = Ions concentration per dissociated solute molecule (Na^+ and Cl^- 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 (20^o C $+273^o$ = 293^o K).

The amount of average concentration of oceans salt 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 = 0.598 mol / liter and the osmotic pressure of seawater is:

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

Since one bar = 100,000 Pascal (Pa) and one kilogram (force) per square centimeter (kg_f/cm^2) = 98066.5 Pascal. Then,

$\pi = [27.1 \times 10^5 \text{ Pa}] / [98066.5 \text{ Pa} / (kg_f/cm^2)] = 27.63\ kg_f/cm^2$

$\pi = [27.63\ kg_f/cm^2]\ [m/100\ cm]\ [1000\ cm^3/liter] = 276.3\ kg_f.\ m/liter$

1) <u>Sea Water Energy Potential</u>*, SW_E

$SW_E = [276.3\ kg_f.\ m/liter]\ [9.80665\ Joule/kg_f.\ m] = 2711\ Joule/liter = 2.711\ MJ/m^3$

[The value of the osmotic pressure in bars /10 = the value of energy in MJ/m^3]

SW_E = [2711 Joule/liter] [1 cal/ 4.184 J] [1 kcal/1000 cal] = 0.6479 kcal/liter

$SW_E = [2711\ Joule/liter]\ [1000\ liter/m^3] = 2.711\ MJ/m^3$

In case of generating power continuously (1 m^3 per sec, of every hour), which is the case with power generation systems, the potential energy of this system is:

$SW_E = [2.711\ MJ/m^3]\ [(1\ m^3/sec)\ (3600\ sec)] = 9.759 \times 10^9\ J$

Since 1 Watt = 1 Joule/Second

$SW_E = [9.759 \times 10^9\ W.s]\ [h/3600\ s]\ [1\ kW/1000\ W] = 2711\ kWh$

[or simply use the relation of 3.6×10^6 J = 1 kWh]

SW_E = [2711 kWh] [24 hrs/day] [365 days/year] = 23.75×10^6 kWh per year

2) <u>Osmotic pressure of multi-salt brine; Dead Sea water</u>

$$\pi = \sum_{i=1}^{n} \Phi_i\, I_i\, C_i\, RT$$

The author's estimation of the Dead Sea osmotic pressure is 225 Bar.

Maher Kelada

*Energy potential is a theoretical value. Realistically, the net recovered amount of the potential energy is modest, and highly dependent on salt concentration. Please refer to MIK Technology article "Seawater Osmotic Salinity Power Reality," posted on January 24, 2010.