Seawater Osmotic Salinity Power Reality

By

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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 ceases to exist! Osmosis is the spontaneous movement of water, through a semipermeable 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 semipermeable 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 an 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.

This phenomenon is attracting the attention of researchers as a means for generating power. It is frequently described in industrial terms such as forward osmosis, ordinary osmosis, direct osmosis, pressure retarded osmosis, etc. The major natural source of osmotic energy is the earth’s rivers and oceans. Many writers enthusiastically point out the potential of mixing one cubic meter per second ($1m^3$/s) of river water and $1m^3$/s of ocean water to generate 2.7 Megawatt of power. Several others have stated that the global potential of this natural source amounts to 1,600-1,700 TeraWatt hour (TWh) annually.

It is a reality that the process of mixing river and ocean waters would generate renewable and practically waste-free power. However, it is a wishful thinking to assume that this source of low density energy can curb the world‘s exceedingly demand for energy. It is unfortunate that no researcher, technical writer or anyone at all has attempted to validate a realistic thermodynamic model of this process to evaluate the actual energy requirements to achieve this global power potential. Research is normally done testing purified solutions in micro-scale bench equipment.

Very few U.S. patents in osmotic power generation were granted in the last four decades. 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.

However, the author of the present article takes exception to certain areas where contradictory or erroneous information were presented that might undermine the value of this work, particularly in large scale high salinity water applications. Osmosis is a source of low density energy. To harness this energy, realistic operating parameters based on actual field conditions must be clearly defined and analyzed.

The subject of this article is to evaluate seawater osmotic power potential, based on sound engineering practices and without bias or excitement. An attempt is made to analyze the few data points that were published by the recent Statkraft of Norway osmotic test and further postulate a scenario for generating osmotic power from the Mississippi River.

The basic theory that Statkraft of Norway has adopted in developing their osmotic power generation pilot plant that was commissioned on November 24, 2009 is based on Loeb's work. Final assessment of that pilot plant has not been revealed, but it is 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(1). Despite scarcity of test information, this data is sufficient to debate the merits of freshwater-seawater osmosis power generation scenario.

The osmosis process for salinity power generation is rather simple and requires few basic unit operations; semipermeable membrane modules (M), solutions pumping means (P) and turbine generator (T) to recover osmotically generated energy. The attached simplified schematics illustrate two arrangements:

1) Arrangement of FIG A analyzes a perfect process that comprises the basic components for power generation by osmosis. This system is hypothetically assumed to function as a perfect machine. This implies that the seawater and freshwater delivery pumps (P1, P2) and power generation turbine (T) operate at 100 percent efficiency. It also implies that there is no imperfection in the rotating equipment, no energy losses due to system restriction and no fouling or membrane's concentration polarization problem.

2) Arrangement of FIG B analyses a realistic process that comprises the same basic components of FIG A, but assuming a realistic efficiency of 75 percent for the seawater delivery pump (P1), 85 percent for the power generation turbine and 60 percent efficiency for the freshwater centrifugal pump (P2). These efficiency values are inclusive of the required energy for filtration and flow delivery within the vicinity of the system.

In both arrangements, seawater (SW) at a rate of $1 m^3/s$ and 3.5 percent salt concentration (mostly sodium chloride) is pumped through one side of the membrane(s), while fresh water, (FW) with negligible amount of salt is pumped along the opposite side of the membrane, preferably in a countercurrent mode. Freshwater in sufficient amount would be transported to allow for a permeate rate equivalent to the seawater flow of 1m^3/s, with an additional capacity to continually flush the freshwater side of the membrane.

In the freshwater-seawater scenario the membrane is rated to permeate water by osmosis from the freshwater side to the seawater side at a rate of 1m^3/s. This means that the flow leaving the seawater side is at a rate of 2 m^3/s, but now at half of the original concentration or 1.75 percent. It should be also clear that the seawater pumping pressure into the system is equivalent to the osmotic pressure of the diluted seawater at the point of leaving the membrane to enter the turbine. In another word, the seawater pump delivery pressure is 196 psi (138 meter) that is equivalent to the osmotic pressure of 1.75 percent salt concentration.

Concurrently, the seawater returned stream (SWR) is now at a higher potential than the seawater feed, since it is doubled in volumetric capacity while maintaining its original differential head of 138 meter. This stream can now be preferentially used to generate energy.

Statkraft is reporting differential head of 120 meter supposedly at 1.75 percent salt concentration. This value implies head loss of 13 percent. This discrepancy appears to be contributed to the inability to maintain concentration differential across the membrane. In most cases this is attributed to membrane concentration polarization(2,3), which is common problem in spiral wound membranes that are designed for reverse osmosis.

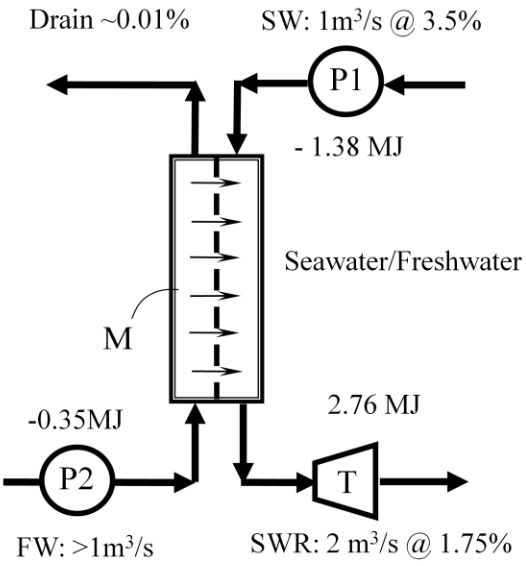

FIG A

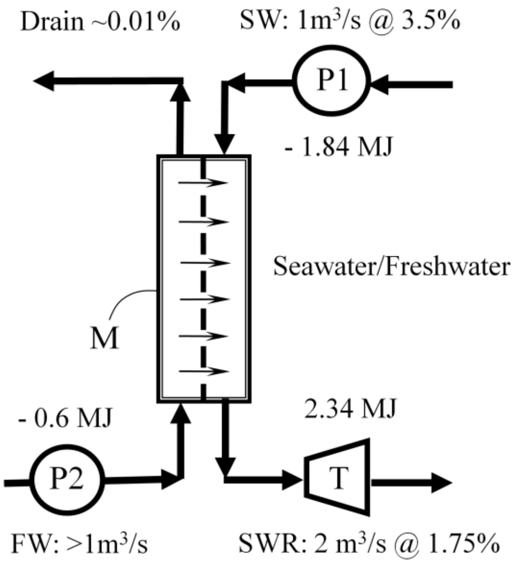

FIG B

The unit of 1m^3/s is a conventional volumetric flow unit in osmosis applications. The rate of 1m^3/s may appear to some as a small amount of water. In fact, the water volume of 1m^3/s, in terms gallons, is about 50,000,000 gallons per day. Water preparation and delivery consumes appreciable amount of energy, which require careful examination before considering any osmotic power scheme.

Results of energy evaluation of the perfect system of FIG A indicate that the pumping requirement for this system is 1.73 MJ/m^3. While the generated energy, corrected for specific gravity, is 2.76 MJ/m^3. This indicates that this system is operating with a positive energy generation of 1.03 MJ/m^3, or about 37 percent efficiency. As it appears, Statkraft objective is to achieve this level of energy recovery (4), astonishingly by constructing a perfect machine!

Energy Estimation	FIG A	FIG B
Equipment efficiency	P1, P2: 100%, T: 100%	P1: 75%,P2: 60%, T: 85%
Potential energy generation (E)	2.76 MJ	2.34 MJ
Total pumping energy (PE)	1.73 MJ	-2.44 MJ
Net energy generation (NE)	1.03 MJ	-0.10 MJ
System Efficiency NE/E	37%	0%
NE/m^3 of brine feed	1.03 MJ	0 MJ & 0 MJ

The energy results of the realistic system of FIG B where pressure drop and equipment deficiency have been considered indicate that the pumping requirement for this system is 2.44 MJ/m^3, which exceeds the turbine generated energy by 0.1 MJ/m^3. This implies that the realistic system is operating with a deficit in energy and it is not economically viable technology.

In light of this information, it would prudent to use reverse engineering to analyze the few data and images that were published by media after the startup of Statkraft pilot plant. This is by no means an analysis of Statkraft system or attempt to undermine their effort and leadership in this field. The objective here is to make some observations that might raise questions about the performance and problems that could be faced in developing the osmotic power technology.

1. If it is assumed that the pilot plant is a perfect machine (100 percent equipment efficiency), then based on the declared power output of 2 KW, the estimated seawater flow should be about 1.94 liter/sec (30 gpm). Such small flow does not justify the large size facility (3,4,5,6) provided, which include six arrays of membranes with each array contains 12 membrane vessels each measuring about 0.1 m in diameter and 1.0 m in length with a surface area amounts to 2000 square meters, the large size of water manifolds (appear as 6-8 inches in diameter), the pumping and the isolation means, etc.

2. Large equipment size imply that Statkraft is either concerned about system pressure drop and intentionally over sized the system to minimize losses, or otherwise the system was designed for higher energy output, but the intended objectives were not achieved. Therefore, the system seems to operate at efficiency much lower than 100 percent.

3. The membrane separation process seems to be affected by concentration polarization since the osmotic pressure relevant to the discharge flow differential concentration; supposedly of 1.75 percent, coincides to osmotic head of 138 meter, was actually 13 percent lower than what it should be.

4. The Statkraft pilot plant is housed in a building where tanks were provided to store brine and freshwater for testing. It is not clear if natural water was transferred via piping system to the testing site from remote sources, supplied by other means or formulated on site. In an actual large scale osmotic power plant the discharge of a river into the sea forms concentration gradient band that extends outwardly for several kilometers. This is a common phenomenon for all world rivers discharging into seas and oceans. To insure constant salt concentration of seawater for osmotic power generation, supply lines have to be extended a long way offshore. This process requires extensive pumping means and transfer piping systems.

It is rather prudent to rely on a realistic large scale example to illustrate the difficulties that can be encountered in implementing a low density energy system such as freshwater-seawater osmotic power generation. In this example, a futuristic scenario is contemplated for generating energy using the osmotic difference between the freshwater of the Mississippi River and the saline water of the Gulf of Mexico. This example calls for installing an osmotic power station rated at 100 MW to meet the City of New Orleans expanding electrical demand. Power recovery premise, as postulated by various literatures, is 2.7 MJ/m^3:

1. To meet the power generation premise, seawater will be pumped at a rate of 100 m^3/s and freshwater rate will be pumped at a rate of 120 m^3/s. The additional 20 percent of freshwater is intended to maintain continuous flushing of the freshwater membrane side.

2. Freshwater could be pumping directly from the river within a close proximity of the power station. A utilities plant is required to treat 2.75 billion gallons a day and pump treated water to the station at a rate of 1,910,000 gpm. Water pumping is done in two steps; from the river to the utilities plant (40 ft head) and from the utilities plant to the power station (75 ft head). Total pump shaft power is 92,600 brake horsepower (bph) or 69,053 KW. This excludes power for utilities plant operation and ultraviolet treatment.

3. Pumping seawater is completely a different story. Here, 100 m^3/s has to be pumped from some point offshore where water salinity is 3.5 percent. It was reported that the north-western Gulf salinity during the month of May near shore waters off Louisiana to Texas Galveston Bay can be less than 2.4 percent. This is inadequate level for salinity power.

4. This mandate that seawater intake be placed several kilometers off shore. At the selected location, a pumping and coarse marine life filtration station of 1,600,000 gpm would be installed on an offshore platform and be powered and manned to pump this water to the osmotic power station on shore. Further treatment of seawater in the utilities plant for sediments and microorganism (specifically plankton) removal is required.

5. Transfer pipe or pipes has to be laid on the sea floor of Gulf of Mexico for the intended length. Based on estimated flow velocity of about 3 m/s, this flow would be transported in one single 6.5 meter (21 ft) pipe, or preferably in six- 9 ft in diameter pipes. Centrifugal pumping energy requirements from the offshore platform to the utilities plant, base on 10 kilometers transfer pipe(s), at a discharge head of 100 ft and 60 percent

efficiency is 67,561 bph or 50,381 KW.

6. Brine pumps at the power station operate at a discharge pressure equates to the osmotic pressure of 1.75 percent salt concentration. At 450 ft head and 75 percent efficiency, the total pump(s) shaft power is 243,221 bph or 181,373 KW.

7. Consideration should be also given to the discharged flow from the osmotic power station. The estimated flow is equal to the sum of seawater and freshwater flows, or 220 m^3/s. This flow rate amounts to 1/3 of Hoover Dam discharge rate. The discharged flow can be returned back to the Gulf presumably in an open canal. Centrifugal pumping energy requirement at 65 ft head and 60 percent efficiency is 97,726 bph or 72,875 KW.

8. Considering the recent Statkraft test experience (7) 100,000,000 square meters or 100 square kilometer of membrane will be required. This estimate would be reduced upon improvement of membrane technology.

In conclusion, large scale osmotic power generation employing freshwater-seawater scheme is a major undertaking with questionable merits and negative economical consequences. Based on the postulated example of New Orleans osmotic power station, total power requirement is 305 MW, while theoretical power generation is 270 MW. The energy deficit is 35 MW, which could be much higher if realistic turbine efficiency of 85 percent is used and if all the miscellaneous power requirements were considered. Energy deficit can amount to 30%. This example substantiates the claim that is outlined earlier in FIG B.

It is seriously doubtful that any large scale project of a similar scheme can generate any significant amount of power. Osmosis energy generation is unlike generation of any other source of energy; oil and gas, solar, wind, nuclear, waves, geothermal, etc. All of those sources are readily available for utilization, requiring insignificant amount of energy to exploit their potentials. However, exploiting the potential of osmosis requires consumption of large amount of energy on continuous bases. Unless there is an appreciable energy margin between generation and consumption, the process is futile.

There is a narrow lane of perplexity and exhilaration between reality and wishful thinking. With perceptive logic and comprehensive scientific evaluation, crossing this lane would be avoided.

Despite the writer's opinion about freshwater-seawater osmotic power generation, the potential for power generation employing osmosis is still incredible. There is a new concept in osmotic salinity power, a patent pending technology that is not limited by water availability in a specific geographical locality. It has the potential of generating several folds the theoretical potential of freshwater-seawater scheme and is doable for much less cost. Still large amount of membrane will be needed, but system's power generation efficiency can be in the 60 percent range.

This new technology could be another topic, but it will be for another day.

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