



OSMOTIC POWER IN LEBANON

Among the different marine energy sources that Lebanon can explore, osmotic energy is the power that is dissipated when water with a relatively low salt concentration meets water with a higher salt concentration. With several fresh water rivers flowing into the mediterranean sea, the osmotic potential of Lebanon is assessed in this CEDRO Exchange.

The CEDRO X-Change Series is kicking off through this Issue, Issue 1, with a study on a little known power sources; Osmotic power. The Exchanges are meant to be reader friendly, i.e., for all types of readers, and yet at the same time offer added value or information to experts in the field. The Exchanges will be released monthly and will reflect the work on RE and EE as implemented and/or assessed by the UNDP-CEDRO Project and/or augmented by Guest Authors and/or organizations. Expected future Exchanges will be touching upon all forms of renewable energy generation and processes in the Lebanese context in general and the UNDP-CEDRO project in particular... Stay tuned!

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Overview

- Lebanon targets a share of 12% of renewable energy in its energy mix by 2020
- Lebanon is a coastal country that could benefit from the energy potential of the sea
- Osmotic energy is promising for areas where river waters meet sea water
- Many Lebanese rivers appear, however, too seasonal to ensure a sensible production of energy
- Osmotic technologies are still in the R&D phase and are expected to be very expensive to compete in the next decade in Lebanon.
- Nevertheless, keeping this power source in mind is beneficial and a revisit is called for post-2020.

Background

Marine energy, in its various forms (e.g., wave, tidal, and osmotic), have yet to be investigated for Lebanon. Although the Mediterranean sea shoreline is characterized as relatively calm, when compared to other places such as the western coasts of the United Kingdom, proper due diligence is required to know whether or not it is hiding unsuspected power.

The purpose of this exchange issue is to estimate the potential of osmotic power recovery in Lebanon and its profitability owing to the development to date of the technology called PRO for "Pressure Retarded Osmosis".

Osmosis Phenomenon

Nature seeks balance. When fresh water meets salted water, they mix until reaching a mean concentration of solutes. This phenomenon releases energy generally dissipated into heat.

This energy potential is clarified in the following experiment depicted by Figure 1. In a recipient divided into two compartments by a membrane permeable for the solvent but not for one or

several solutes, pour fresh water in one side, and salty water in the other, then wait and observe the outcome. Fresh water progressively migrates through the membrane to dilute the concentrated solution, thus increasing the water level of this side, and decreasing the other. The pressure resulting from the level differential between the two is precisely the differential of the osmotic pressures in the two mixtures. Energy can be recovered from this pressure.

It is against the osmotic pressure that desalination processes have to struggle, which explains the very high pressure and the amounts of energy that these processes use.

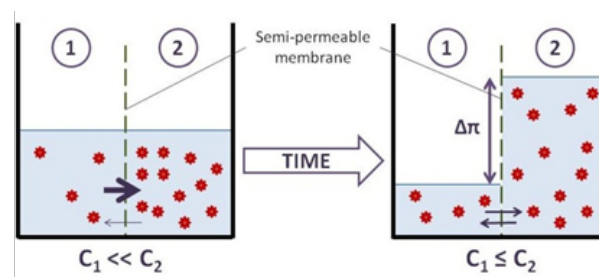


Figure 1: The osmosis phenomenon

Technologies of Osmosis

Recovery of the osmotic pressure

Recovering the osmotic pressure is equivalent to making compartment #2 of Figure 1 push on a mechanical device that will be able to convert the pressure into electricity or directly use it (desalination, production of hydrogen, pressurised storage, etc.). The simple case of Figure 1 is called forward osmosis (FO). To optimise the recovery, the more concentrated mixture must be under pressure below the osmotic pressure differential; this is pressure retarded osmosis (PRO). This technology is mainly developed by the Norwegian producer Statkraft. Lastly and especially used by desalination processes, the principle of the process called reverse osmosis (RO) is to apply a pressure above the osmotic pressure differential in order to force the water to cross the membrane from the concentrated side to the dilute solution, thus increasing the osmotic pressure of the salted solution. All those definitions are illustrated by Figure 2 below.

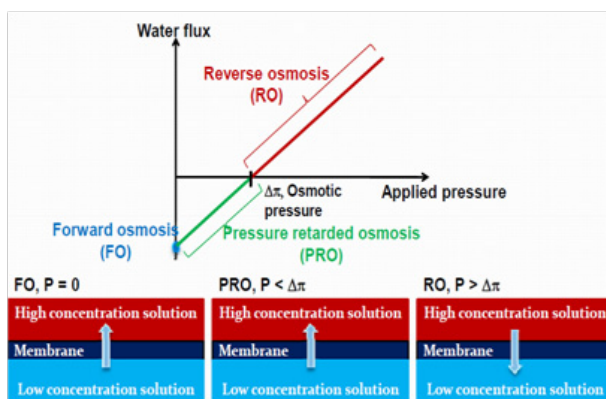


Figure 2: FO, PRO, RO, the different osmotic technologies (Tang, 2010)

Recovery from the ionic circulation

Another way investigated to recover osmotic power is the reverse electro-dialysis (RED), led by research done by Wetsus in the Netherlands. The purpose herein is to create an electrical current by making anions circulate along one direction and cations along the opposite one across sophisticated membranes. The process appears less efficient than PRO to date, and will not be further assessed here. Further information can be found in Ramon et al., 2011.

Technical Box

Theory of Pressure Retarded Osmosis

Each mixture x has an intrinsic osmotic pressure π_x , which does not depend on the nature of the solutes. The Van't Hoff Law approximated for diluted solutions describes the osmotic pressure expressed in Pascal:

$$\pi_x = \frac{RT_x}{V_x} \sum_{i=1}^p n_{i,x}$$

R is the universal gas constant, T_x is the temperature of the mixture x in Kelvin, V_x its volume in cubic meter, and $n_{i,x}$ the quantity of each substance in mole.

The pressure differential between two mixtures 1 and 2 is simply $\Delta\pi = \pi_2 - \pi_1$.

The following theory is given by Achilli et al., 2009. Introducing the *permeability* A of the membrane used to recover the osmotic pressure differential, the flux of solvent across the membrane, expressed in cubic meter per second and per square meter, is described by:

$$J_w = A(\Delta\pi - \Delta P)$$

A is expressed in cubic meter per second, per Pascal and per square meter. ΔP is the hydrostatic pressure differential between the two mixtures, expressed in Pascal, and J_w is positive when the direction of migration of the solvent is natural, from the less concentrated solution to the more concentrated.

Lastly the specific power, in watt per square meter of membrane, is given by $W = J_w \Delta P$, and is maximum when $\Delta P = \frac{\Delta\pi}{2}$. Membranes are generally wounded in cylindrical units.

World Osmotic Potential
1,600 to 1,700 TWh/year (Statkraft)
This is 1.2-1.3% of current world energy
consumption

Lebanese Osmotic Potential Assessment Data

The main data required for studying an osmotic potential are the salinity of sea water and river water, generally expressed in practical salinity unit (psu, equivalent to gram of solutes per kilogram of solvent), and the flow of the river exploited. Data availability in Lebanon for the above parameters is, however, scarce. This study relied solely on one river measurement point for which both flow and salinity were recorded by the Office National du Litani, specifically at the station of Qassmiyeh on the Litani river (see Figure 3).

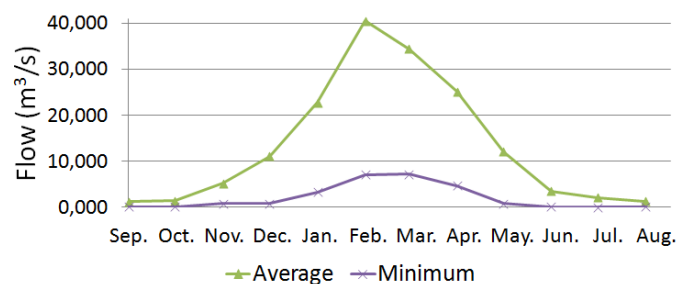


Figure 4: Monthly averaged and minimum flows of the Litani river at Qassmiyeh station

Salinity has been measured once a month over only one year, but the lack of data about the salinity of the river has less impact than imprecise data about the salinity of the sea. The average of 0.317 psu has been used.

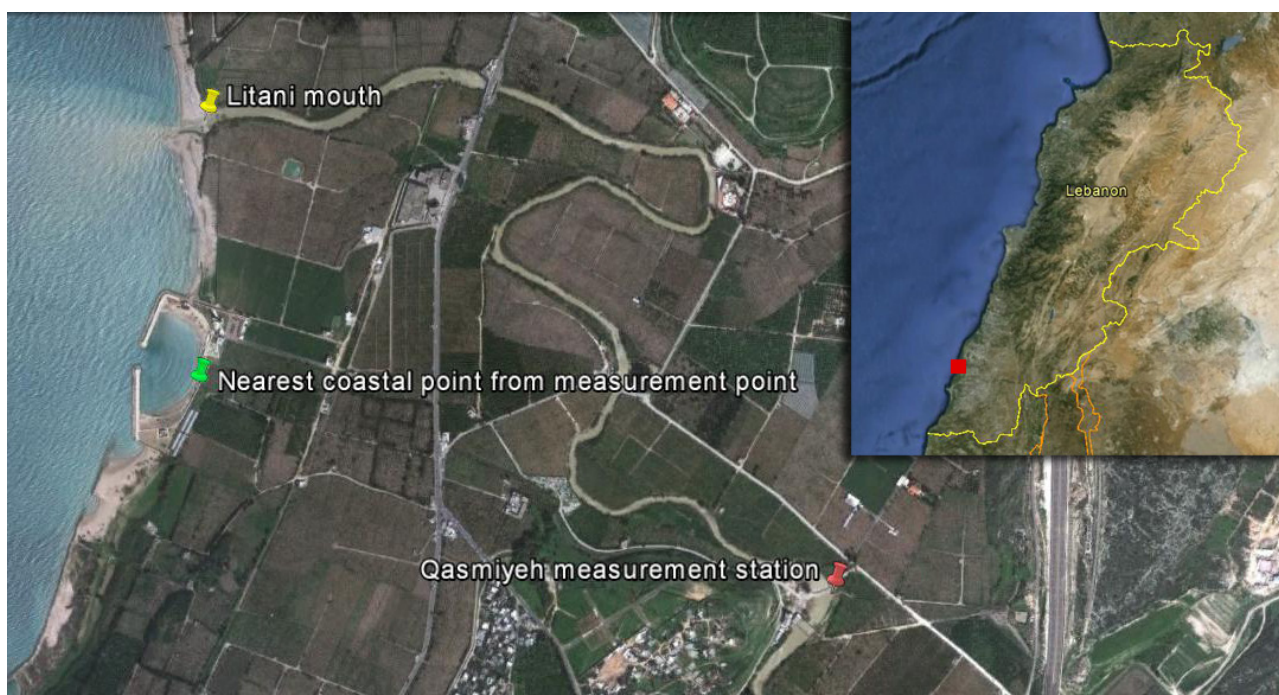


Figure 3: Position of Qassmiyeh station on the Litani river

Flow data is daily recorded over 12 years. Monthly averaged and minimal flows are charted on Figure 4.

The economic data have been extrapolated from information that Statkraft makes public through its website, its press releases and its presentations in conferences such as the biannual Osmosis Membrane Summit (OMS). Some economic data also come from other participants in these OMS.

Assumptions

Extrapolations from data available have led to the consideration of two types of units assuming current and expected future costs. A first type of unit is similar to those experienced in the prototype of Statkraft, with 308 m² of 1.3 W/m² membrane while the second type of unit is similar to those expected for the demonstrator that Statkraft plans within five years, with 1,000 m² of 6.6 W/m² membrane. Assumptions used to determine the performance and economics of the systems are indicated in Table 1 and are adopted from several sources, including MEW (2010), Maritime Communication Services et al., (2008), Achilli et al., (2009), Lakkis (2004), and Statkraft web-portal.

Parameters	Value
Pressur of sea water at inlet	15 bar
Pressure of low pressure flows	1.5 bar
Part taken from the river flow	10 %
Trans-membrane transfer rate	85 %
River Water/Sea Water	0.5
Brine to pressure exchanger	70.175 %
Pumps efficiency	70 %
Pelton turbine efficiency	80 %
Alternator efficiency	95%
Costs	Value
Electricity cost	
Investment costs	\$c17.14/kWh
Fixed cost	\$1,500,000
Unit cost (proto, current)	\$6,000/unit
Unit cost (proto, future)	\$3,000/unit
Unit cost (demo, current)	\$80,000/unit
Unit cost (demo, future)	\$40,000/unit
Maintenance	2%/year
Temperatures	Value
River water	21 °C
See water	23°C

Table 1: Overview of assumptions

Environmental Concerns

Osmotic power generation can become a renewable energy source. But the exploitation is eco-friendly only if some issues are addressed.

First, the river flow cannot be entirely recovered, because the rivers and their banks shelter a rich ecosystem. In this study, a rate of only 10% of the flow is used in the osmotic process. Biologists should recommend the upper limit of water withdrawal, and the means to do this without disturbing wildlife.

The withdrawal of sea water is not so problematic, but should also follow the advice of specialists.

The chemical products used for the maintenance and water pretreatments are required to limit the bio-fouling of the membrane, but should not pollute the river or the sea after rejection in nature.

Electro-mechanical efficiencies have been arbitrarily set to 70% for the pumping system, 80% for the Pelton turbine, and 95% for the alternator.

Results

The osmotic pressure differential at Qassmiyeh is:

$$\Delta\pi = \pi_{sea} - \pi_{Litani} = 30,2 \text{ bar}$$

Though the natural osmotic power collected by the plant designed for a maximum production of electricity is 5.2 MW, the electric power output is only 310 kWe, due to the turbine and alternator efficiencies, but mainly to pumping works. This means that the maximum electrical production is 880 MWh/year although the energy resource used to produce this electricity is 14,800 MWh/year. This huge gap is obvious in Figure 5.

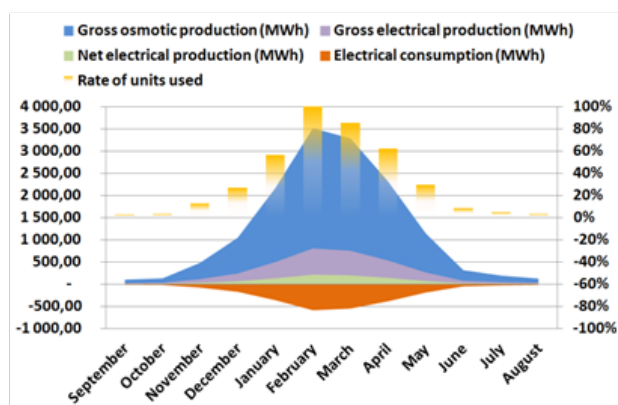


Figure 5: Maximum production and consumption of an osmotic power plant at Qassmiyeh with performances of Statkraft demonstration plant

When looking at the rate of units used each month, it is noticeable that they are all used only in February, when the Litani river flow is at a maximum. From June to November, less than 15% of the capacity is useful, and even less than 3% from August to October. To get to profitability, units must obviously be fewer, but continuously used all year long.

Lebanese Osmotic Potential

Extrapolating roughly the results obtained at Qassmiyeh, where a natural osmotic technical potential of 148 GWh/year has been assessed, the national natural osmotic potential should be around 1 TWh/year. This figure has to be compared with the global osmotic potential (see Box in page 2).

But considering the limitation of water withdrawal, the operating energy costs of recovery plants, and assuming at least six other river flows like Qassmiyeh along Lebanon's coast, the national osmotic potential of electricity generation should be 5 to 6 GWh/year. 11,522 GWh of electricity were provided by Electricité du Liban in 2009 (MEW, 2010).

The economic potential, however, is another issue, and is not encouraging at the moment.

In economic terms, the most interesting design has the net electrical output as depicted in Figure 6.

With this design that uses only 101 membrane units with performance of the demonstration plant planned by Statkraft, 250 MWh/year would be produced. All units are used seven months out of twelve, and 20% of the units, at least, are functioning at any time. However, taking into account the maintenance costs and the consumption of electricity required to pressurize the sea water (see Table 1), the plant would lose almost 70,000 \$/year. If the electricity produced by the PRO plant would benefit from a feed-in tariff of \$c25/kWh, the plant would breakeven.

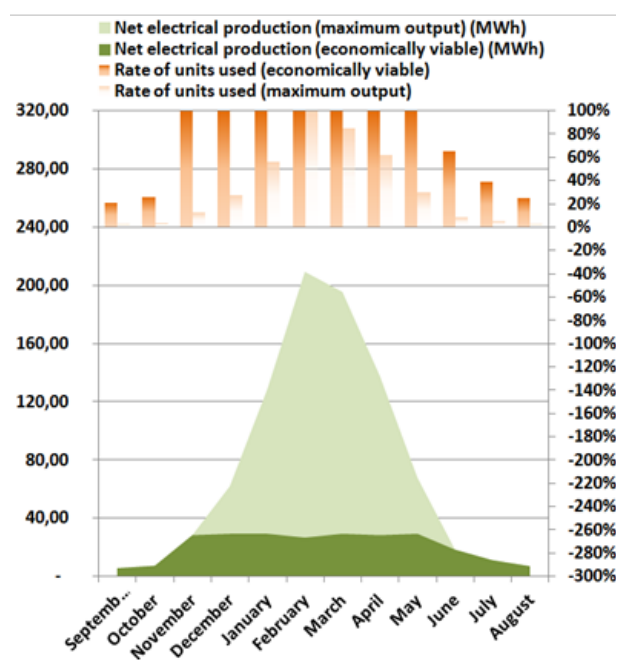


Figure 6: Comparison of net electrical outputs of the maximum design and the most economically efficient design of an osmotic power plant at Qassmiyeh with performances of Statkraft demonstration plant

Targeting a bankable plant, the adjustment of a single criterion has not enough influence, or is out of reasonable range. Only a combined evolution of all criteria can lead hopefully to an economically viable osmotic plant at Qassmiyeh. Such a set of parameters is presented in Table 2.

Criteria	Variation	New value
Electricity cost	16.7 % (+)	20.00 USC/kWh
Investment cost	9.9 % (-)	6,803 \$/kW
with Units cost	12.5 % (-)	35,000 \$/unit
and Fixed cost	33.3 % (-)	1,000,000 \$
River Water/Sea Water	x2	11/
Pelton turbine efficiency	6.3 % (+)	85 %
Pressurization of low pressure flows	20 % (-)	1.2 bar
Part taken from the river flow	50 % (+)	15 %
Trans-membrane transfer rate	3.5 % (+)	88 %
Pumps efficiency	4.3 % (+)	73 %

Discussion & Conclusion

Osmotic power currently appears to be a marginal source of energy for Lebanon. The maximum potential for the Litani river, the main river in Lebanon, is around 310 kW of net electrical production. The national capacity would hardly exceed 2 MW or approximately 5-6 GWh/year of net electrical production, which represents electricity supply for around 2,000 households, and represents less than 0.1 % of the national capacity needed in 2009 (MEW, 2010). And with amortizable plants based on PRO technology, the maximum capacity would be around 250 kW for the whole country, equivalent to 250 households' consumption, and not much than 0.01% of the capacity needed. Moreover, those capacities correspond to the best month of production, whereas Lebanese rivers are highly seasonal.

The PRO technology, not yet mature, could turn amortizable quickly within the next 10 years, thanks to developments and technological leaps expected. Focus points for a technology watch are about the costs and efficiency of membrane units, and about membranes' lifetime and resistance to fouling. However, as most Lebanese rivers are characterized

by very seasonal flows, the viability in Lebanon would hardly meet the gross osmotic potential; osmotic power appears economically interesting to recover with rivers whose flows are as constant as possible year round.

Given the current situation of the electricity sector in Lebanon (see MEW, 2010), the real cost of electricity and its likely increase in the coming years, any energy source must be considered, including osmotic power as part of a renewable energy mix, with the advantages of varying continuously over the year and being precisely predictable, which means a base-load generation source in a totally eco-friendly way. But as said above, it will remain at the margin because of low river flows.

This study recommends a re-visit of Osmotic Power in Lebanon post-2020, yet must do so after establishing an accurate measurement of river flows (at their mouths). Biologists should have also assessed which maximum proportion of the river flows that can be taken in a way that respect wildlife. Thanks to the first experience in other countries, the energy and financial costs of the pretreatments required for water and the costs of the pumping works should be available. With all these precisions, if an implementation appears feasible, more subtle issue such as the diffusion of solutes throughout the membrane or the dilution of the bulk of sea water along the membrane should have to be investigated.

Non-reused wastewater can also be used as "fresh" water in the process, because of a mean salinity of only two or three times the salinity of rivers. As most of wastewater is rejected to sea, it is simple to think about using it and taking power from them just before rejection. As for rivers, wastewater flows and salinity should be collected over some years to have all data at disposal when the technology will be mature and cheaper enough to be reconsidered in Lebanon.

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