Power Production based on Osmotic Pressure.

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Abstract

The mixing of freshwater and seawater where rivers flows into the salty ocean releases large amounts of energy that can be used for power production. The pressure retarded osmosis (PRO) process will operate with filtered fresh water pumped into modules containing membrane. In the module fresh water migrates through the membrane and into pressurised seawater. The flow of diluted and pressurised seawater is then split in two streams where one is depressurised hydropower turbine to generate power, and the other passes through a pressure exchanger in order to pressurise the incoming seawater.

The two key components in a PRO plant are the pressure exchanger and the membrane. Since 1997 the Norwegian utility company Statkraft, a company with a strong tradition in hydropower, has engaged in technology development aiming at cost-effective Osmotic Power production. Today Statkraft is the world leader in development of Osmotic Power, and have made state of the art achievements during the last few years.

The work has resulted in the design and production of a semi-permeable membrane optimised for Osmotic Power. As an example, the current power density of the membrane is approximately 3 W/m2, which is up from less than 0.1 W/m2 a few years back.

The world's first prototype plant will be put into operation in 2009 in the southeast of Norway. The main objectives of the prototype are twofold. Firstly, confirming that the designed system can produce power on a reliable 24-hour/day production. Secondly the plant will be used for further testing of technology achieved from parallel research activities to substantially increase the efficiency. These activities will mainly be focused on membrane modules, pressure exchanger equipment and power generation (turbine and generator). In addition there will be a focus on further development of control systems, water treatment equipment, as well as infrastructure with regards to water inlets and outlets.

Osmotic powers excellent environmental performance and CO_2-free power production will qualify for green certificates and other supportive policy measures for renewable energy. The estimated energy cost is comparable and competitive with the other renewable energy sources. For both the commercial power companies and technology suppliers this means that Osmotic Power represent an attractive new business potential.

CONTENT:

1. Background

The pressure on the environment by human activities and especially with carbon dioxide emissions being at all time high calls for alternatives to be thoroughly researched. Since the Kyoto protocol in 1997, the call for reducing carbon emission has been intensified. Oil and gas reserves are restricted and will with the current pace be depleted within some decades. EU has adopted ambitious targets for energy and climate with 20 percent of energy consumptions from renewable sources, 20 percent reduced green house gas emissions and 20 percent increased energy efficiency put in place by 2020.

The major source of low cost, conventional energy globally is fossil fuels. The use of fossil fuels will continue to be the major source of energy the next decades. Nevertheless, as the global consumption of energy is growing, there will be a need for new renewable energy sources as well as reduction in the use of fossil fuels as an energy source.

Besides climate and environmental considerations, R&D is about business survival and growth ambitions, meaning that we need to create a better balance between improvements of existing technologies and be well prepared to build new renewable solutions.

We are searching for alternative carbon dioxide free energy sources. Such energy sources could be offshore wind, wave and tidal, photovoltaic, and osmotic power. Statkraft, a Norwegian utility company with a strong tradition in hydropower, has been engaged in technology development attempting to develop new renewable energy technologies. Since 1997 one of these development areas has been to aim at cost-effective Osmotic Power generation.

2. Osmotic Power, a new renewable source of energy

The mixing of freshwater and seawater where rivers flows into the salty ocean releases large amounts of energy that can be used for power production. The pressure retarded osmosis (PRO) process will operate with filtered fresh water pumped into modules containing membranes. In the module fresh water will move through the membrane towards the pressurised filtered seawater and dilute it. The flow of diluted and pressurised seawater is then split in two streams where one is depressurised through the hydropower turbine to generate power, while the other stream passes through a pressure exchanger in order to pressurise the incoming seawater.

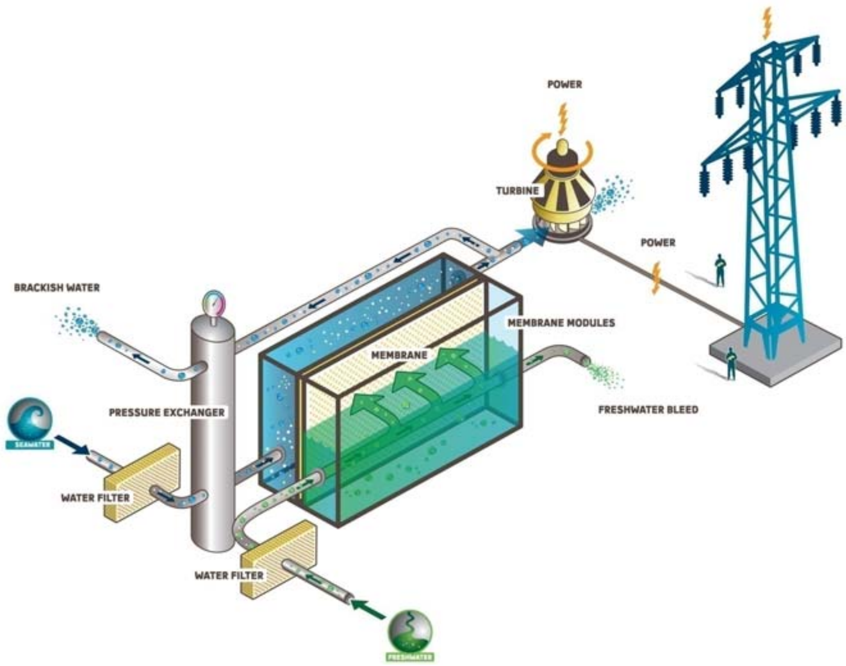

Illustration text: *The principle of osmotic power is utilising the entropy of mixing water with different salt gradients. In the process the water with low salt gradient moves to the side with the higher salt concentration and creates increased pressure due to osmotic forces. Given the sufficient control of the pressure on the salt water side, approximately half the theoretical energy can be transformed to electrical power, meaning that the operating pressure are in the range of 11-14 bars enabling the generation of 1 MW per m^3 per sec fresh water.*

The higher the gradient between salinity in the fresh- and saltwater, the more pressure will build up in the system. Similarly, the more water that enters the system, the more power can be produced. At the same time, it is important that the fresh water and sea water is as clean as possible. Substances in the water may get captured within the membranes support structure or on the membrane surfaces, which will reduce the flow through the membrane causing reduction in power output. This phenomenon, which is called fouling, is linked to the design of the system, to the characteristics of the membrane, and to the membrane element.

Membrane development.

The membrane should have characteristics that make it suitable for PRO, meaning high water permeability, low salt permeability and low resistance in the support layer of the membrane. Low affinity to fouling substances is also desirable a requirement.

The development of a membrane especially designed for PRO has been the main focus since Statkraft got involved in 1997 with one of the aims being to develop a cost-effective membrane. The target for a PRO membrane is to generate 5 W/m^2 net to produce power at a cost which is comparable to other renewable energy sources. The work has resulted in the design of a semi-permeable membrane optimised for Osmotic Power. As an example, the current power density of the membrane is approximately 3 W/m^2, which is up from less than 0.1 W/m^2 a few years back. These achievements show that we are getting closer to a real application in this process which stated as a mere idea.

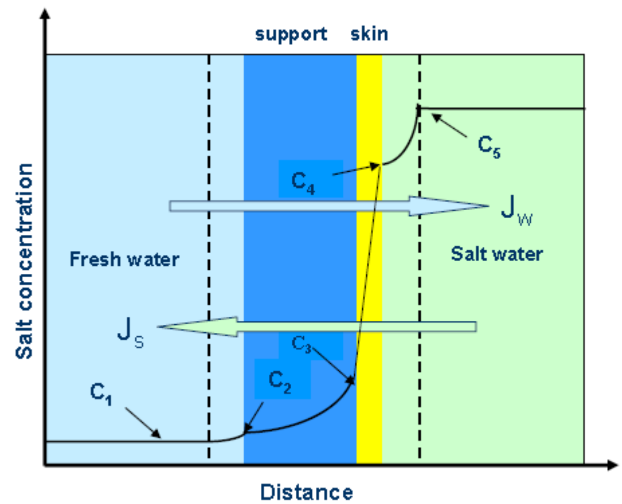

Illustration text: *The flow conditions for a typical PRO membrane.*

The fresh water (J_W) flows through the support and the skin into the sea water which is diluted. The salt in the salt water (J_S) flows through the skin of the membrane and the support into the fresh water. The figure shows the salt gradient through the system. C_1 is the salt concentration in the bulk of the fresh water, C_2 is the salt concentration at the interface between the fresh water and the membrane support, C_3 is the salt concentration at the interface between the membrane support and the membrane skin, C_4 is the salt concentration at the surface of the membrane skin, while C_5 is the salt concentration in the bulk of the salt water. The figure illustrates that there is a considerable salt gradient in the membrane support, which is the difference between C_3 and C_2. This salt gradient must be minimized, achieved by having a thin and open structured support which allows fast diffusion of the salt molecules into the fresh water. Likewise it is important to minimize the salt gradient at the sea water side ($C_4 – C_5$) and the salt gradient at the fresh water side ($C_2 – C_1$) which is achieved by having sufficient velocity across the membrane in both the sea water and the fresh water channels on each side of the membrane. The salt gradient across the membrane skin ($C_4 – C_3$) much be as high as possible which is obtained through high water permeability and a low salt permeability of the membrane.

The membranes are fitted into membrane elements containing a specific amount of membrane area. In the desalination industry the so-called spiral wound element design and the hollow fibre design are the most common cost effective designs. Statkraft is working on developing these designs to fit with the special requirements for PRO. The design criteria are, that the elements must be able to have flow on both the fresh water and the sea water side of the membrane, the elements must contain a large membrane area, fouling must be minimised, and the design must be cost effective.

Osmotic Power potential

The fresh- and seawater feed should ideally be free of any contaminates. However, the water contains to a varying degree contaminants that have to be dealt with by suitable pre-treatment, membrane characteristics and membrane cleaning or process operation.

Sufficient freshwater quantity in one of the most crucial requirements, and the first water quantity assessments for the Osmotic Power potential were based on a methodology which used average discharge and low flow discharge values, where the latter was defined as the 80 percentile from duration curves. The rationale for this is that the average discharge only will give an overview of the usual water flow in the river in question, and the 80 percentile will give an indication on how low the water discharge is 20 % of the days during a year. I.e. minimum discharge measured in more than 80 % of the time period. Resulting in a reasonable measure of how much water can be extracted from a given river, and the potential duration of dry periods with limited water for power generation.

There are a number of more detailed factors that need to be considered when assessing the regional or local potential to find the resource availability in order to build Osmotic Power plants. These are illustrated by:

- The amount of water in the river, especially during low flow periods
- The freshwater and sea water quality, due to the risk of fouling of the membranes
- The characteristics of the membrane and the membrane element used, in particular its ability to withstand fouling of polluting substances
- The physical and chemical conditions in the estuary

These factors will be essential to determine whether or not the development of a commercial PRO power plant is economically viable. Some additional factors must be taken into consideration. For instance, lateral river migration may be a challenge in some areas, as river channels are not always stable systems. Erosion and deposition of particulate material may cause the channel to change its form and pathway over time. Typical areas where this occurs are areas subject to significant land use changes, areas with heavy erosion processes, or areas where the downstream parts of the rivers run through low-lying land without erosion protection works. Any installations in delta areas should therefore be preceded by riverine assessments in order to determine the risk for channel migration.

Another important factor is that the present use of the estuary may be in conflict with the construction of a power plant. Often, estuaries are zones of extensive human activities, including boat traffic, urbanisation, and extraction of water for different purposes including industrial use or irrigation.

Several marine estuaries are also protected against development due to different environmental reasons (bird protection, national parks, special heritage sites, etc.). It is usually possible to obtain an overview of these protected areas in each country by consulting maps of natural heritage or national park zones.

It is important to note that feasibility studies must be carried out for each individual river before a power plant is developed. However, based on average discharge and low flow discharge values mentioned above the power potential has been calculated globally to impressive 1600-1700 TWh. In Europe there is a potential to generate 180 TWh, and in Norway alone 12 TWh – equivalent to 10% of the total power consumption in Norway.

3. Environmental aspects

Osmotic Power is a renewable energy source with no CO_2 emissions. The mixing of seawater and freshwater is a process that occurs naturally all over the world. The Osmotic Power plants will extract the energy from this process without interfering with the environmental qualities of the site, and the process produces no other significant effluents that will interfere with the global climate.

A possible source of harm on the local area is the impact of the brackish water on the local marine environment. Brackish water is the main waste product of Osmotic Power, and the discharge of brackish water into the marine environment may alter the environment and result in changes for animals and plants living in the local location.

However, most of the rivers run into the ocean in a city or an industrial area. This means that most of the Osmotic Power potential can be utilised without constructing power plants in unspoiled areas. In already developed areas the effects on the estuary are changed adversely. Controlled and careful building of the inlet, plant and outlet for an osmotic power plant can improve the present condition of biotopes of the river, the estuary and the sea.

This means that most of the osmotic power plants can be build without constructing in unspoiled areas. The plants can be constructed partly or completely under ground and would fit well into the local environment. In these areas the environmental impact on shore are estimated to have a limited impact with regards to grid, roads, etc.

4. The first PRO plant

In the previous chapters it has become clear that a lot of effort have been necessary to increase the conviction that osmotic power can be a viable technology for producing renewable energy. The understanding of the critical challenges and also the improvement made for membranes suitable for osmotic power has significantly increased the expectations for moving PRO from an interesting, theoretical concept into a promising new technology. Similar improvements have been made on the development of technology for regeneration of the hydraulic pressure.

The fall 2007 Statkraft decided due to the promising improvement on the critical components as membranes and pressure recovery devices, the time had come for a full-scale proof of concept for a complete PRO system. A plant should be build where sufficient amount of membranes were installed to transfer salinity gradient into work and also further into electricity. At the same time as the interface and integration for all the components in the system can be studied together in operation, not only as individual parts of a system.

After a little more than a year of development and construction, the world’s first prototype plant will be put into operation in spring 2009 in the southeast of Norway. The location is within the facility of a pulp factory in operation, which simplifies the approval process and at the same time gives good access to existing infrastructure. In addition the location has good access to sea water from the ocean, and fresh water from a nearby lake.

The prototype plant is designed as a typical plant placed at sea level. Freshwater is taken from a river close to its outlet. Seawater is fed into the plant by underground pipes, and the brackish water is lead to the natural brackish water zone.

Illustration text: *The prototype at the East coast of Norway*

The main objectives of the prototype are twofold. Firstly, confirming that the designed system can produce power on a reliable 24-hour/day production. Secondly the plant will be used for further testing of technology achieved from parallel research activities to substantially increase the efficiency. These activities will mainly be focused on membrane modules, pressure exchanger equipment and power generation (turbine and generator). In addition there will be a focus on further development of control systems, water pre-treatment equipment, as well as infrastructure with regards to water inlets and outlets.

The plant is equipped with 2000 square meters of specially designed PRO membranes, a miniature hydropower turbine and devices for recovery of hydraulic pressure are installed. Although the design capacity is in the range of 10 kW, the expectations for the capacity in the first phase will be somewhat less. The membranes have room for improvement, and there are high expectations for optimisations for the whole system as such.

Since this is the first plant build for PRO operation, severe precautions have been taken to make sure that possible pollution in the water does not destroy the membranes. For the sea water regular pressure screens are used, and for the fresh water from the lake the pre-treatment is similar to that being used for drinking water. The ambitions are that the fresh water can be treated similar to the sea water. This will however be based on the operational experiences.

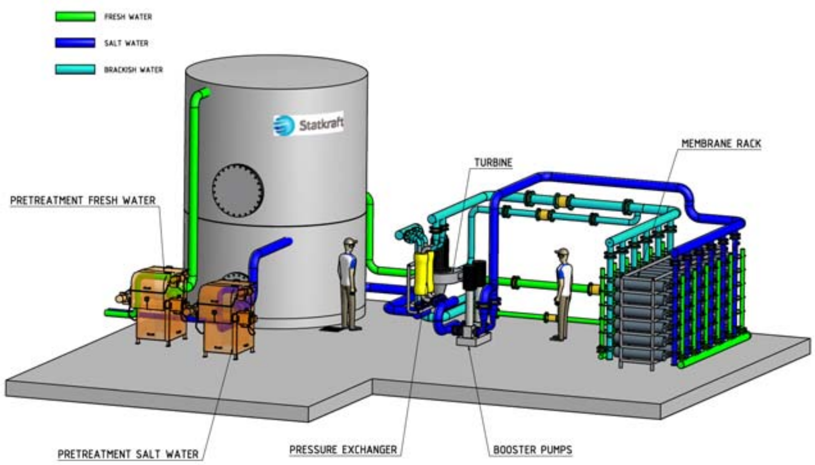

Illustration text: *Prototype illustration*

After the start-up, operation and further testing the experience gained will be based on both operational changes as well as changes to the system and replacement of parts. This is in order to increase the efficiency and optimize the power generation. In a longer perspective this would be used as a basis to develop a power plant with installed capacity between 1-2 MW, bringing the technology one step further towards commercialisation.

The prototype plant put into operation during 2009 is also intended as a meeting place for parties both from government and industry with ambitions in Osmotic Power. With the increasing focus on the environmental challenges and the need for more renewable energy, this can give a significant contribution to increase the momentum in development of new clean technologies.

5. Financials

Osmotic Power is one of the most promising renewable ocean energy sources. In order to utilize this form of green energy, the membrane, the heart of the process, has to be optimized. Osmotic Powers excellent environmental performance and CO_2-free power production will qualify for green certificates and other supportive policy measures for renewable energy. The estimated energy cost is comparable and competitive with other renewable energy sources.

The estimated costs of producing one MW based on a number of detailed investment analyses it is expected that Osmotic Power will be able to produce electricity at a cost of Euro 50 - 100 per MW. This is in a similar range as other renewable technologies such as wind power, wave and tidal power and power based on biomass.

These calculations are based on existent hydro power knowledge, general RO desalination engineering information, and with the membrane target as a prerequisite. The capital cost of installed capacity is high compared to other renewable energy sources. However, each MW installed is very productive, with an average operation time above 8,000 hours a year. This should generate approximately twice the energy supplied (GWh) per installed MW per year compared to a wind mill.

To achieve competitiveness, given the large volumes of membranes, the membrane pricing is important. An average 25 MW plant is calculated to need 5 million m^2 of membranes, meaning that the industry would see a demand of PRO membranes exceeding the current RO membrane market.

Additional challenges for the moment includes that the equipment are not yet developed to the level of efficiency required, the energy cost is sensitive to membrane efficiency, and in the system the membranes are vulnerable to fouling.

An effort to address these issues and alternative development designs needs to be addressed further in the future in order to prevent these issues to become commercial barriers.

A common ground for the development should be established with public and private research institutes as well as energy companies involving themselves in order to develop more large scale pilots and demonstrations projects. This indicates the expectations that in order for this technology to soon become commercially viable there is a need for involvement from several parties.

For both the commercial power companies and technology suppliers this means that Osmotic Power represent an attractive new business potential.

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