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Osmotic power — power production based on the osmotic pressure difference between waters with varying salt gradients

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Abstract

Statkraft engaged in the development of osmotic power technology in 1997, and is today the most prominent developer of the osmotic power technology in a global context. The commercialisation of osmotic power is dependent on large volumes of sufficiently efficient semi-permeable membranes with high flux and salt retention. In addition to developing the technological concept and critical parts of the system, such as the membrane technology, Statkraft has also identified the energy potential, the financial aspects and the environmental implications of the technology. Osmotic power stands out as a promising and yet unexploited, new renewable energy sources. Throughout the last years, Statkraft has been successful in its furtherance of the necessary membrane technology and has recently started the detailed planning and design of the first osmotic power prototype plant in which it will further verify and test the technology.

Keywords: Statkraft; Osmotic power; PRO; Pressure retarded osmosis

1. Background

Since the Kyoto protocol in 1997, the call for reduced carbon emissions has been amplified all over the world. Authorities have followed up on the agreements and amongst others increased public support for sustainable environmental-friendly energy production. That has led to a bounce in the numbers of new renewable power generation projects, ranging from wind power, through bio-energy, solar and ocean power to a number of new nuclear power plant projects.

Osmotic power is a relatively new energy conversion concept even though osmosis has been known for several hundred years. Only 30–35 years ago, Prof. Sidney Loeb and his team utilised the natural knowledge and proposed methods for the utilisation of osmotic pressure in power generation using membranes.

In the eighties and nineties, membrane technology was introduced successfully in many industrial applications and efficient semi-permeable membranes became available. In the late nineties

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the efficient transfer of mechanical energy between fluids was also made possible. All the basic technology components necessary for efficient osmotic power production were therefore in principle available and a team at the Norwegian research organisation Sintef under Mr. Thor Thorsen furthered the concept.

Statkraft, a North European power producer and a company with a strong hydropower tradition, has engaged in the research and development of osmotic power and enabling technologies since 1997. Today, Statkraft, with its international membrane R&D-partners, is the main active technology developer globally and hence an osmotic power knowledge hub. The team has made state of the art achievements in terms of new and more energy efficient membrane technology during the last few years.

In addition, Statkraft has identified the commercial potential and environmental limitations of osmotic power and is now planning to build an osmotic power plant prototype to further verify the system and membrane technology.

1.1. The power of osmosis

When placing a semi-permeable membrane (i.e. a membrane that retains the salt ions but allows water through) between reservoirs containing waters with differences in salt gradients, a net flow of water towards the saltier water side will be observed because of osmosis. Given a fixed volume compartment on the saltier side, the pressure will increase towards a theoretical maximum of 26 bars for seawater applications. This pressure is equivalent to a 270 metres high water column.

1.1.1. The process of osmotic power

The principle of osmotic power is utilising the entropy of mixing water with different salt gradients. In this process water is transported spontaneously through a semi-permeable membrane from the side with the water with low to the water with the higher salt concentration and creates increased pressure due to osmotic forces. The increased pressure produced through the osmosis can be utilised in various forms, also easily in a turbine. We have found that pressure retarded osmosis (PRO) is the most promising method for production of this energy. The principle of a PRO power plant is sketched in Fig. 1.

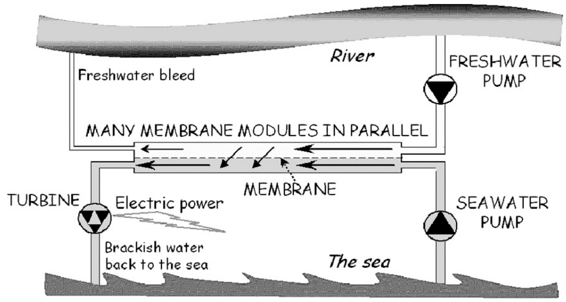

Fig. 1. Principle of osmotic power plant.

Given sufficient control of the pressure on the salty water side, approximately half the theoretical energy can be transformed to electrical power, making osmotic power a significant new source of renewable energy.

1.1.2. The PRO process

In the PRO process, water with no or low salt gradient is fed into the plant (greyish) and filtered before entering the membrane modules. Such modules could contain spiral wound or hollow fibre membranes. In the module, 80–90% of the water with low salt gradient is transferred by osmosis across the membrane into the pressurised salty water (bluish). The osmotic process increases the volumetric flow of high pressure water and is the key energy transfer in the power production process. This requires membranes with particularly high water flux and excellent salt retention properties.

The illustration in Fig. 2 shows salty water pumped from the sea and filtered before it is

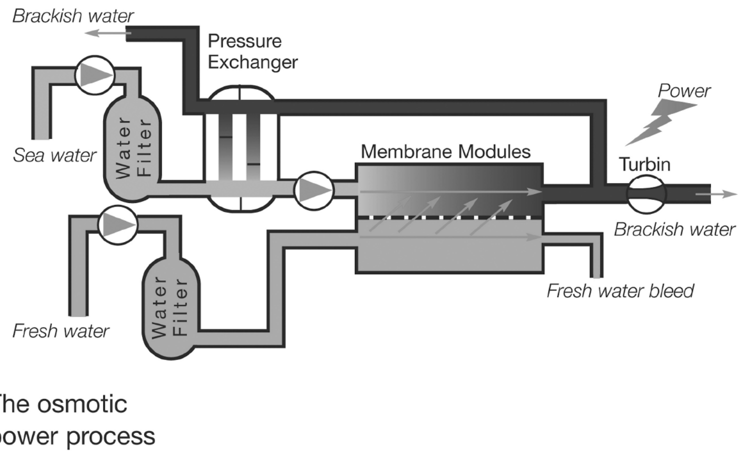

Fig. 2. A simplified PRO process diagram.

pressurised and fed into the membrane module. In the module it is diluted by the water received from the less salty side of the membrane. The volumetric feed of salty water is about twice that of the fresh water.

The diluted and now brackish water (dark blue) from the membrane module is split in two flows. While ca. 1/3 of the brackish water is fed though the turbine to generate power, 2/3 is returned and energy is recycled in the pressure exchanger to add pressure to the feed of salty water. Optimal operating pressures are in the range of 11–15 bars, equivalent to a water head of 100–145 metres in a hydropower plant, enabling the generation of 1 MW per m^3 s fresh water. The fresh water feed operates at ambient pressure.

Pre-treatment of the water will be necessary depending on the water qualities. In Norwegian water treatment plants, mechanical filtration down to 50 μm, in combination with a standard cleaning and maintenance cycle has been enough to sustain the membrane performance for 7–10 years.

2. The results

Statkraft early recognised the development of a PRO membrane with high flux and salt retention as the main challenge of osmotic power commercialisation.

While most components of a complete osmotic power plant were located for optimisation, the PRO membrane theory needed detailing and the hypothesis to be tested. Statkraft therefore employ large resources, both money and manpower, in the search for the key membrane technology.

The Salinity Power project was established in 1999 to analyse the feasibility of osmotic power. It was partly financed by the European Commission (contract no ENK6-CT-2001-00504). The project was successfully finalized in 2004 and had then established a strong understanding of the osmotic power system, verified the theory as well as the potential but also revealed the need for further technological progress.

Since then, Statkraft has continued its efforts to develop osmotic power. In addition to the intensive research on membranes, Statkraft is analysing the system and the energy potential further, surveying the environmental implications and detailing the investment analysis.

2.1. System analysis

To enable the commercialisation of osmotic power, the flexibility and adaptability of the power plant has been of major concern. Statkraft has therefore performed studies of various designs of viable osmotic power plants, and a selection of these has been modelled in flow-models to compare the efficiency and energy production under different site and placement conditions: At sea level, sub-sea and below sea level placement. With the location of the plant just a few meters below the sea level it is possible to reduce the number of pumps to the minimum and the efficiency to 81%. Therefore, the overall energy efficiency of a plant just below sea level is significantly higher than a plant at sea level but also than a plant in the sub-sea design.

The system is described in the patent No 0314575B1 and a similar patent pending for the EPO.

2.2. Membrane development

The development of a membrane especially designed for PRO has been the main focus since the very beginning of Statkraft's involvement. In early estimations, it was established that the PRO membranes needed to generate at least 4 W/m^2 net to produce power at a sensible cost.

Commercially available RO membranes tested first, but it was soon realised that they only produced modest efficiencies of less than 0.1 W/m^2 utilised in a PRO process and therefore were unsuited. Statkraft therefore decided to develop special PRO membranes to reach the targeted membrane performance. Starting from less than 0.1 W/m^2 in 1999, Statkraft and its partners have lately been able to verified power production well above 3 W/m^2 under laboratory conditions (Fig. 3).

In close co-operation with its scientific partners, Statkraft will continue its efforts to develop the optimal PRO membrane. Improving the membrane performance to about 4 W/m^2 net in PRO operation and up-scaling the membrane units is currently the major focus and Statkraft has therefore decided to invite industrial partners to take part in the membrane development.

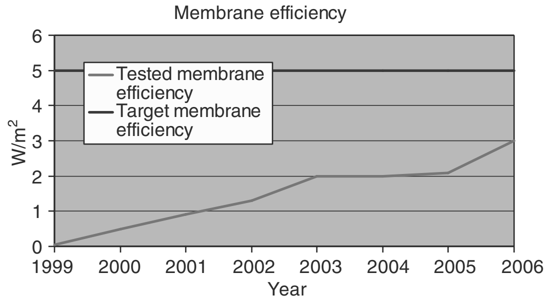

Fig. 3. Development and future targets of PRO membranes.

The aforementioned patent also describe the membrane necessary to achieve efficient osmotic power production.

2.3. Environmental aspects

Statkraft wish to be a European leader in environmental-friendly energy production. Osmotic power is a completely sustainable energy source and therefore fulfils Statkraft's major investment prerequisite, the environmental friendliness.

The mixing of sea water and fresh water is a naturally occurring process. Osmotic power plants are designed to utilise the power potential in this process without major interference with the environmental qualities of the site.

Interestingly, most rivers around the globe run into the ocean in a city or an industrial community. This means that most of the osmotic power potential can be utilised without constructing power plants in unspoiled areas. As discussed previously, the power plants can be constructed partly or completely under ground and would thus blend well into the local environment.

Statkraft has assessed the environmental optimisation and pre-environmental impact of an osmotic power plant located at a river outlet and not found any serious obstacles. A combination of river flow regulatory compliance and careful engineering of the intake and outlet of brackish water would reduce the impact on the river environment to a minimum.

The operation and maintenance of an osmotic power plant will be similar to that of a regular water treatment plant, for which the impact on the local environment is well documented. In fact, Statkraft has also developed a way to backwash the PRO membranes that could prove to be particularly environmentally friendly compared to the use of cleaning chemicals as they are used in water treatment today.

2.4. Energy potential

Statkraft has analysed the exploitable potential for this new source of energy and while the hydrology facts have convinced Statkraft that the potential is huge, further detailed research has been commissioned. New studies will show to which extent osmotic power plant sites are available.

The major technical prerequisites of osmotic power plant sites are (1) steady availability of fresh water and sea water (2) available building site at or beneath the surface. Statkraft has envisaged such sites at river mouths or outlets from hydropower stations situated close to the ocean.

Limitations are both of natural and environmental kinds. Extremely variable water flows would for example restrict the inclusion of a particular river in the analysis, as would also some environmental regulations that regulate the use of rivers or the coastal waters.

Statkraft has analysed the osmotic power exploitation potential, utilising a hydrology based methodology. In Norway, the technical potential is estimated to about 12 TWh/year, equivalent to ten per cent of current Norwegian power consumption. In Europe outside Norway the similar potential is estimated to ca. 170 TWh/year, while the potential in the rest of the world is roughly estimated to ca. 1475 TWh/year. Hence, the total estimated potential for osmotic power is estimated to ca. 1655 TWh, in line with the combined annual supply in Germany, France, Spain and the UK.

The osmotic power generation potential is huge also compared to other renewable and unexploited energy sources. In comparison, globally, 2645 TWh of hydropower is utilised today (2003), about 33% of the economically viable potential.

2.5. Investment analysis and price forecast

Statkraft has developed detailed investment analysis and have strong reasons to believe that the future prices of renewable energy will fully cover the investments and allow a competitive margin. In the calculations, costs are based on Statkraft's experience from hydro power projects and general RO desalination engineering information.

There are obvious challenges: As in most membrane based technologies, the PRO membrane is maybe the most important component of the osmotic power plant. Given that an average 25 MW plant in our calculations will need ca. 5 mill m^2 of PRO membrane, the growing industry would very fast demand a volume of PRO membrane by far exceeding the RO membrane market of today.

The capital cost of installed capacity is high compared to other renewable energy sources such as wind. Each MW installed is however very productive. While a wind mill is designed to operate in average 3.500 h/year at various capacities, an osmotic power plant is designed to operate at full capacity for more than 7000 hours a year, generating roughly two times the TWh per installed MW per year.

The competitive pricing range for osmotic power is expected to be EUR 50–100/MWh in the short term, taking into account the support functions available for other renewables today and in the future. To achieve competitiveness, given the large volumes of membrane in an osmotic power plant, the membrane pricing is of utmost importance. Statkraft expect that the cost of osmotic power production will be in line with the cost of wind offshore and below wave and tidal power generation in 2010–15.

3. Discussion

Based on the analysis reviewed above, Statkraft believe that osmotic power represents an exiting new renewable energy source with a strong commercial potential. Technological, environmental and commercial feasibility is established and will be verified through further studies and the prototype that Statkraft is currently designing.

3.1. Technology

Technically, as discussed above, the final development of the PRO membrane with the right technical and cost properties is essential to allow for realistic production of osmotic power. The same is true for the pressure pipes and some other system elements, such as the availability of highly efficient pressure exchanger devices.

Much of the technology known by the hydropower and the desalination (water) industries today can be transferred to osmotic power plants with small modifications. An osmotic power plant will for example need membranes, pressure exchangers, pressure vessels, filters, pumps and pipes. For the water industries, osmotic power could therefore represent a large and welcome new business potential.

With 5 million m^2 membrane per 25 MW (enough to produce the electricity need of ca. 8000 households) installed osmotic power generation capacity, the successful exploitation of the osmotic power potential will lead to a major increase in the demand for membranes (PRO). In order to exploit 10% of the estimated European power potential, about 500 million m^2 of membrane will be needed.

3.2. Environmentally

Osmotic power is a highly sustainable renewable energy source and therefore expected to receive support similar to that received by wind and solar power today. The environmental analysis has not revealed any significant obstacles. Nevertheless, the availability of the fresh water will probably limit the potential of osmotic power to areas with river water running into saltier water.

3.3. Commercially

To achieve commercial feasibility, the cost calculation must be verified and short to medium term the support schemes in place for other renewable energies must also be available for osmotic power.

The demand for renewable energy sources is lately demonstrated through a number of reports indicating climate changes and the need to review and change the use and generation of energy. Over the next decade, reports indicate multiples of today's investments in renewable energy generation.

We believe supported osmotic power will be competitive compared to other renewable energy sources, such as wind, tidal, wave and to a certain degree also hydro power. In addition, longer term, we believe that it will be competitive also compared to the marginal capacity expansions based on a market price of electricity.

The last years of wind power development have created a fast growing, new market for installations and services. A similar market will evolve as osmotic power is commercialized and the potential is exploited.

4. Conclusion

In this paper, we have sought to introduce the reader to the concept of osmotic power and the latest developments on the way to commercialisation. Osmotic power stands out as a promising and yet unexploited new, renewable energy sources. Statkraft will therefore continue its efforts to develop osmotic power into an available source of new renewable energy source for the near future.

The most prominent challenge is the PRO membrane efficiency. The membrane chemistry must be optimised, final designs must be developed and manufacturing must be up-scaled. To exploit the full potential, Statkraft has decided to invite commercial membrane producers to discuss membrane development partnership. To verify our analysis and to seek further knowledge of the osmotic power process and the system while at the same time creating a test ground for osmotic power elements, Statkraft has decided to plan the building of an osmotic power plant prototype. After proof of concept in the prototype, a full scale demonstration plant and introduction to the energy market will follow.

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