Osmotic Power: A Future Inexhaustible Energy Source

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ABSTRACT:

Energy is one of the major inputs for the development of any country in this world. The sources of energy which we are using today will no last long for too many years as they are diminishing day by day. Osmotic power generation is one of the alternative source which can significantly contribute to fulfill the world's ever growing thirst for energy. This paper foresees the concept of osmosis, existing methods to utilize osmotic energy, membrane development, it's cost and cleaning, advantages, disadvantages and challenges to overcome.

Keywords: Osmotic power, Pressure retarded osmosis, Renewable energy source, Reverse electro-dialysis, Semi-permeable membranes

I. INTRODUCTION:

The fossil fuels (i.e. coal, oil), animal dung, firewood and nuclear cause the atmospheric pollution, CO_2 emission, deforestation, water masses pollution and leads to global warming. These energy sources are diminishing with time; where at the another side the energy requirement of each and every country is increasing for their future development. The 80% of world's population lies in the developing countries where their energy consumption is only 40% and the developed countries have 20% of world's population whose energy consumption is 60%. Both the situations indicates that it is necessary to go for an alternative energy source and one of those alternative source is osmotic power.

The world's first implementation of osmotic power plant was done by the Statkraft on 24 November 2009 with the capacity of 4kW in Tofte, Norway. This plant uses polyimide as a membrane and is able to produce $1W/m^2$ of membrane. This amount of power is obtained at 10 L of water flowing through the membrane per second; at pressure of 10 bar. Both the increasing of the pressure as well as the flow rate of water would make it possible to increase the power output. Hypothetically, the output of the SGP-plant (Salinity Gradient Power Plant) could doubled easily.

Osmotic power is released naturally at the deltas and estuaries (i.e. the part of the river where it joints the sea) because the freshwater of the river strives to mix with seawater. Osmosis can be defined as 'the process in which solvent molecules pass through a semi-permeable membrane from a dilute solution (hypotonic solution) into a highly concentration solution (hypertonic solution). In this process, the water molecules present in the freshwater pass though a semi-permeable membrane into highly saline seawater. This is due to the difference between salt concentration of the both. The membrane used in this process acts as a filter which

allows only small tiny molecules such as water molecules though it. Therefore the water molecules which are passed through the membrane creates high pressure to the other side. This generated pressure is utilized to gain energy in the form of electricity by using turbine. The main problem in this energy source is to overcome the high cost of the membrane as the membrane cost 50-80% of a power plant.

Energy created by osmosis process has very less impact on environment. This is a renewable energy source as the river and ocean are available in abundance and additionally, the process does not consume salt. The power generation potential of salinity gradient is 2.6TW where the power generation potential of ocean waves is 2.7TW, thermal gradient is 2.0, and of tides 0.03. The osmotic pressure difference between the freshwater and seawater is equivalent to 26 bars which is equivalent to the hydraulic head of 270m. This shows the osmotic power is overall beneficial with each of its possibilities.

II. METHODS TO UTILIZE OSMOTIC POWER:

There are several methods to utilize the osmotic power or energy such as pressure retarded osmosis (PRO), reverse electro-dialysis (RED), capacitive mixing (CAPMIX), etc. The PRO and RED technique requires membrane and the CAPMIX technique required different kinds of electrodes.

1) Pressure Retarded Osmosis (PRO):

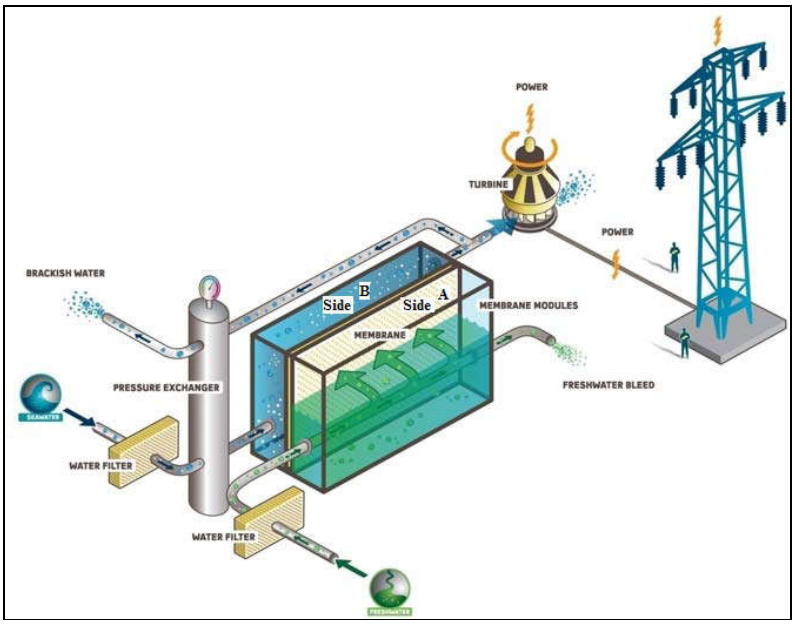

Fig.1: PRO Power Plant[4]

PRO power plant setup consist of closed water chamber divided by a semi-permeable membrane in which a filtered freshwater is fed into one side and the seawater is fed into another side i.e. side A and B respectively. The freshwater is at ambient temperature and the saltwater is pressurized at 11-15 bars(equivalent to hydraulic head of 100-145 m) by pressure exchanger. The difference between the salt concentration of freshwater and saltwater creates a strong force towards mixing. Due to this, freshwater strives to mix with

seawater and passes through the small or tiny holes of a semi-permeable membrane. Generally, 80-90% of the freshwater passes through the membrane and volume in the side B increases. The water chamber is closed; hence increasing volume creates pressure due to the redistricted area. This generated osmotic pressure generally depends upon salt concentration of seawater which can be in the range of 24 to 26 bars. The pressurized water flow is drawn out through outlet port from the side B of chamber. This pressure is utilized to run a turbine for electricity generation.

The problem in this setup is, after neutralization, decreasing salt concentration of seawater results to slow down the process. By continuously making the both side of chamber empty and then refilling it again can fix this problem; but this must be done quickly to avoid run-interference. Hence there is an additional outlet port to the side A to withdrawn the remaining freshwater. The only byproduct of this setup is the pressurized brackish water (neutralized dilute water) is further divided into two flows in which 1/3 flow is given to the turbine and 2/3 flow is given to the pressure exchanger to increase the pressure of the seawater.

2) Reverse Electro-dialysis (RED):

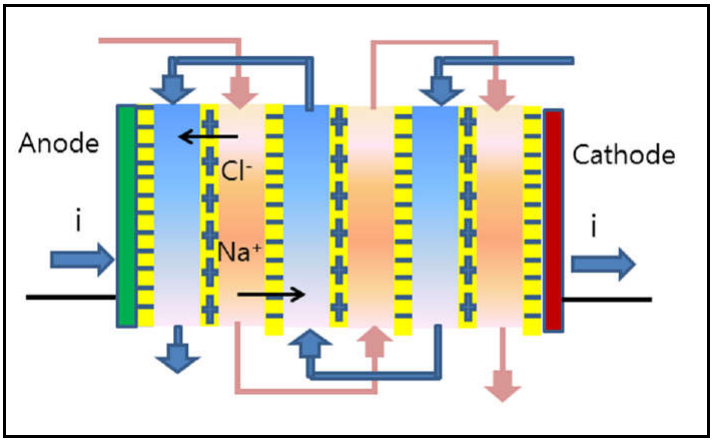

Fig.2: Reverse Electro-dialysis[6]

It is revolutionary technology that can be used to convert the controlled mixing of two solution into electricity. The salt in the seawater consist of positively charged ions and negatively charged ions. The ions are present in freshwater too, but in smaller concentrations. When the ions are allowed to move between the two solutions, they tend to move from high to low concentration to balance the difference in salinity between the sea and freshwater. Special membranes are used to control the process which allow only negatively or only positively charged ions to pass through it (e.g. ion-selective membranes).

By placing the membranes in an alternating way between the seawater and the freshwater, the ions are forced to move in specific directions generating a current that can then be easily converted by electrodes into an electrical current. Freshwater has a low concentration of ions which limits the amount of electricity that can be produced by in the power plant. If we use seawater as the low concentration solution and mix with a very high saline concentration i.e. brine solution; hence by introducing much more salt into the process we can overcome one of the technologies limiting factors enabling us to produce the much more electricity.

III. MEMBRANE:

It is an organic filter having extremely tiny holes which allows only small molecules like water molecules to pass through it. Osmosis process is depends on a thin layer material of membrane. The membrane should have high water flux and high salt retention property. In general, performance or power density of membrane should be in the range of 4-6W/m^2. Mostly, in the RED process ion-selective membranes are used and in PRO process semi-permeable membranes are used. These membranes are used in the osmosis power plant requires larger area for high output; hence they are packed/rolled or coiled to save the space. As a part of packing or coiling them, they are wounded into modules. These modules have characteristics of a large membrane area in a small volume.

There are different types of membrane modules such as spiral-wounded, hollow fine fibres, capillary fibres, plate and frame, tubular, etc. The spiral-wounded membrane modules are used in PRO process. They are resistant to high pressure and less sensitive to fouling a compared to others. A standard spiral wounded membrane module has a 20cm diameter and 100cm length; up to 30cm diameter and 150cm length larger modules are also available but they are manufactured by only few manufacturers. It is possible to achieve a packing density of spiral-wounded membrane modules between 300-1,000m^2 membrane surface area per 1m^3 membrane module.

IV. COST OF THE MEMBRANE:

Initial cost of the membrane was above 400€/m^2, but later as per the development or use of new materials such as polyethylene has reduce this cost over recent two decades to 5€/m^2. This cost is including the pressure vessels and connections related to membrane. Many experts have indicated that within a few years, it will be possible to produce membranes at a cost of 2€/m^2. The figure shows the graph of decreasing cost of membrane over the period of years.

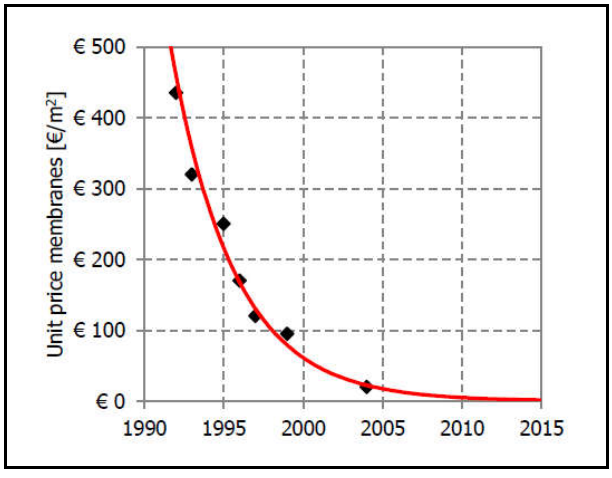

Fig.3: Reduction in Membrane Cost[8]

The above cost of membrane is based on ion-selective membranes used in RED power plant. Hence, the cost of the semi-permeable membranes is comparatively lesser as they have larger pore size and easy to manufacture than ion-selective membranes.

V. CLEANING OF MEMBRANE:

The cleaning and the maintenance of a membrane is also important as much as the cost consideration. It increases the working life of a membrane which results in cost saving of a power plant. To improve the productivity of the membrane a periodic cleaning is necessary which removes foulant materials. Fouling means deposition of different inorganic and organic substances over the surface of membrane. These substances are called as foulants. In synthetic salt water inorganic foulants such as iron, aluminum, calcium, sodium, and silica are found and in this seawater above foulants in addition with magnesium and potassium are found. Organic foulant found are humic substances, polysaccharides and proteins, etc. in both synthetic salt water and seawater. Cleaning can be done by two types i.e. physical cleaning and chemical cleaning. These cleanings are only suitable for PRO process.

i. PHYSICAL CLEANING:

It consist of flushing a demineralized water with the same surface velocities over the both sides of a membrane. This cleaning is done once per week from starting of the experiment. Physical cleaning can be done by membrane backwashing method. In this method, high saline water is used on the feed water side and a water with lower salinity is used on the draw side in order to produce a negative water flux to clean the membrane surface. Generally, this method is not used due to its negative effect on the osmotic driving force i.e the agglomeration of salt inside the foulant layer during cleaning and its low efficiency for water flux recovery.

ii. CHEMICAL CLEANING:

In this type, cleaning of both sides of membrane with the help of a combination of acidic and basic cleaners is involved. Some important parameters that should be considered in chemical cleaning are cleaning agent type, cleaning agent concentration , temperature, pH, flow rate, and cleaning time. It is also necessary to choose a suitable cleaning agent which is compatible with the membrane because some cleaning agents damage the membrane surface and reduce its performance irreversibly. The temperature is kept constant (e.g. 35ºC) by using a water bath to increase the effectiveness of chemical cleaners. This cleaning is also done once per week. As the efficiency of the chemical cleaners to remove the foulants from the membrane surface depends upon the contact time between foulants and chemical cleaners, the total time required for flushing is more than the physical cleaning. The water flux recoveries using chemical cleaning were much higher than those using physical cleaning. It shows the chemical cleaning is significantly effective for removal of foulants as compared with physical cleaning.

VI. ADVANTAGES:

1) It does not emit CO_2 gas hence it is a clear and green energy.
2) Available in the abundant source as it is produced from river and sea water.
3) Maximum energy production in minimum area.

4) It is a renewable energy source as solar or wind power.
5) There is no fuel cost for osmosis process.

VII. DISADVANTAGES:

1) As compared to other energy sources, it is costly.
2) Repeatedly maintenance is required in every week for longer life of membrane.
3) The brackish water can affect marine life.
4) Polyethylene membranes do not biodegrade easily.
5) It is not economically feasible as compared to fossil fuels.

VIII. CHALLENGES TO OVERCOME:

1) Cost of membrane should be reduced for cost effective power plant.
2) Discovery of development of new materials of membrane which will be cheap, easily available and biodegradable.

IX. CONCLUSION:

As per as the increasing need of energy is concerned, osmotic energy is a good energy source in future. If we overcome the current big problems such as membrane cost and its cleaning the osmotic energy source is one of the top abundant energy sources.

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