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Desalination of seawater by successive
heating of thin layers of water using
solar radiations from a Fresnel
concentrator

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1. Abstract

The seawater desalination technique presented in this article is based on a new technique for the production of water vapor which has the advantage of using solar energy with maximum evaporation efficiency. This innovation is limited to the production of steam and can be combined with a known technique of condensation of the steam in order to complete the desalination cycle of seawater. This technique is based on the simple principle that the heat transferred from the hot source to the cold source is maximum if the difference between their respective temperatures is kept at its maximum. Thus, by carrying out successive operations of heating thin layers of water, the technique makes it possible to maximize the efficiency of the evaporation by bringing the temperature of the fluid to its initial value at each iteration, thus enabling, according to the Newton's law, to favor the transfer of heat to water.

Then, in this paper, we present the theoretical demonstration of the soundness of this technique by using the analogy with electricity using the equivalent resistance for circuits in parallel. Next, an application of the technique which is the subject of a patent of invention is presented in the detail. It is a desalination engine for seawater using solar radiation from a Fresnel concentrator. The presented invention makes it possible to produce steam continuously by heating thin layers of sea water by the Fresnel concentrator. The development prospects of the invention are also presented using the techniques of Nanotechnology.

2. Introduction

The seawater desalination technique presented is entitled 'Desalination of seawater by successive heating of thin layers of water using solar radiations from a Fresnel concentrator'. It has the advantage of using clean energy and allows a better evaporation yield. In addition, the most common current desalination techniques are thermal techniques and reverse osmosis techniques. These techniques have the disadvantage of producing greenhouse gases and are not based on clean renewable energies. However, few innovations based on clean energies have emerged recently, including 'the Nanophotonics enabled solar membrane distillation for off-grid water purification' carried out by the Newt consortium. (<http://www.pnas.org/content/114/27/6936>).

Thus, in the context of desalination of seawater for drinking water production, the efficiency of evaporation and the nature of the energy source used are two determining factors in meeting more stringent and more demanding requirements related to the use of renewable energy. In this context, the present article has two very specific objectives:

1. Introduce the principle of improving the efficiency of evaporation of water under the effect of hot plates by subdividing the water to be evaporated into several volumes with thin thicknesses.
2. Introduce the seawater desalination engine by solar radiation using the Fresnel concentrator as application of the stated principle.

3. Principle of evaporation of water under the effect of hot plates by layers of water with thin thicknesses

3.1 Assumptions and evaporation yield :

Two evaporation scenarios of an amount of water of volume 'V' are considered under the effect of horizontal heating plates :

- **Scenario 1** : The whole quantity of water is heated until evaporation by a single horizontal heating plate as shown in the following figure (figure-1):

Figure-1

- **Scenario 2 :** The same quantity of water in Scenario 1 is subdivided into several quantities of the same cross-section as Scenario 1 but of thin thicknesses, of quantities dV , heated by several heating plates as shown in Figure (Figure-2) Below where the sum of the volumes dV is the volume V :

Figure-2

- The yield of evaporation is defined as follows:

$$y = 1 / (Q * t)$$

Where t is the time taken to evaporate the quantity of water desired and Q the amount of heat expended

3.2 formulation of the principle :

The evaporation yield of volume V for scenario2 is better than scenario1:

$$y_{\text{scenario2}}(V) \gg y_{\text{scenario1}}(V)$$

3.3 Theoretical proof :

The proof of this principle is based on the analogy with the world of electricity where it is proven that the thermal resistance in the scenario2 is extremely lower than that of the scenario1. Indeed, it is considered, firstly, that the temperature difference between the heating plate and the fluid corresponds to the electrical voltage. Then the electric current is considered as the amount of heat transferred per unit time according to Newton's equation for convective heat transfer :

$$dQ_{\text{Transferred}} = h \cdot (T_{\text{plate}} - T_{\text{fluid}}) \cdot dS \cdot dt$$

Where h is the convection factor and dS the element of contact surface.

Thus, by analogy with electricity, scenario 1 has a series circuit and the thermal resistance is expressed :

$$R_{\text{th}}(\text{Scenario 1}) = 1 / (h \cdot dS)$$

Furthermore, in Scenario 2 there is a circuit in parallel and the equivalent thermal resistance is expressed:

$$1 / (R_{\text{th}}(\text{Scenario 2})) = 1 / (R_{\text{th}}(\text{Scenario 1})) + 1 / (R_{\text{th}}(\text{Scenario 1})) \dots$$

Thus

$$R_{\text{th}}(\text{Scenario 2}) = R_{\text{th}}(\text{Scenario 1}) / N$$

Where N is the number of subdivisions of the water quantity in Scenario 2.

Conclusion :

The heat transfer is maximized in scenario 2. Thus, with an infinite number of subdivisions, an infinitely large evaporation yield is reached.

4. Application : Solar water desalination engine using the Fresnel concentrator

4.1 Presentation of the Fresnel concentrator

The Fresnel concentrator is a mirror device that reflects the solar rays by reflection so as to concentrate them in a central region as shown in the following figure (figure-3).

The advantage of the Fresnel concentrator is its relatively low cost because it does not use advanced solar technologies but simple flat and parabolic mirrors.

Figure-3

4.2 Presentation of the seawater desalination engine by Fresnel concentrator

Figure-4

The engine

Description :

The operating principle of the seawater desalination engine is based on the use of interleaved and raised cylinders as the salt water pipes in the absorbent tube of the Fresnel concentrator. The water circulating in the annular spaces is evaporated successively until reaching the central point of the tube.

According to the principle stated in point 3., the yield of evaporation is infinitely large for thin and numerous annular spaces. The water would be evaporated under these conditions almost instantaneously. In addition, in reality, the more we have nested and raised cylinders, the more effective evaporation is obtained. On the other hand, the vapor produced can be collected in a transparent tube containing and then condensed by an appropriate technique as required.

The advantage of the engine presented is that it uses renewable clean energy and offers encouraging evaporation efficiencies compared to the techniques known so far. It also offers the possibility to increase production by duplicating the device at will in sites suitable for exploitation. In addition, based on the Fresnel concentrator, the cost of the device is relatively low.

4.3 Numerical simulation of the continuous flow and heat transfer

In order to evaluate the performance of the device presented, it is appropriate to simulate the water flow and evaporation scenario. Such a simulation can be done using a numerical method such as the finite element method which allows to represent complex geometries. However, two possible models exist for modeling fluid flow and heat transfer. The first would be based on the continuous solution represented by the Navier Stokes equations. This model would be recommended for relatively large annular spaces at the micrometer scale. However, if we want to simulate fairly thin spaces on the scale of hundreds of nanometers, the Lattice-Boltzman model would be more suitable in this case.

On the other hand, in order to complete the model, it is necessary to quantify the energy delivered by the Fresnel concentrator by a software tool such as System Model Advisor (SAM). However, for a feasibility study, a simple estimate based on experience would be sufficient to result in a conclusive simulation.

4.4 Perspectives of Nanotechnology applications for thinner dimensions of water layers

The efficiency of the device becomes infinitely large for thinner annular spaces. Thus, at the nanometric scale, the production of steam would be almost instantaneous. Thus, the application of nanotechnology techniques to further increase heat transfer would open up new horizons of evolution of the presented technique.