Sea Transport of Fresh Water

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Abstract. A modular automatic sea transport for the delivery of clean drinking fresh water has been proposed. Transport can be in underwater and surface versions. The transported fresh water and the surrounding seawater can be used as a source of energy for the movement and control of vehicles. Power plants based on osmosis or reverse electrodialysis are considered, as well as their possible joint use of plants of both types.

1. Introduction

Recent research by the International Water Management Institute has shown that more than a third of the world’s population is already experiencing an acute shortage of fresh drinking water. There is also a problem with the quality of drinking water. Regional overpopulation and many factors of human activity pollute the environment and reduce access to a source of life - drinking water. The extraction of water from soil and rivers in these areas is ahead of renewal. The problem is partially solved by the desalination of seawater and the transportation of water by tankers. Pure water, which can be consumed without preliminary purification, can be found only in remote ecologically clean areas. Several percent of humanity has access to high-quality natural drinking water.

2. Relevance

After desalination of seawater with the addition of drinking quality, for example, in the UAE, the cost of 1m³ is $ 500. The average cost of 1m³ of pure natural drinking water without purification is $ 5. The cost of drinking purified natural water rises to $ 20. The wholesale cost of 1m³ for delivery by tankers, due to the shortage of the tanker fleet and the rise in metal prices, has increased 7 times over the past 3 years and is $ 90. Delivery of water by tankers has become unprofitable even in the case of runoff water and is possible only in exceptional conditions. cost of drinking purified natural water rises to $ 20.

3. Statement of the problem

Russia has significant reserves of clean river (channel) waters in the sparsely populated sea coasts of Siberia and the Far East. The authors set the task to increase the profitability of transportation of natural wastewater of clean fresh water by sea transport with minimal construction and maintenance costs. A modular automatic sea transport with a capacity of 100,000 tons, with a propulsion system powered by the difference in salinity of the transported fresh water and the surrounding sea water, is considered. We have previously considered a similar underwater transport for transporting goods using other energy sources [1].
4. Theoretical part

With the reversible mixing of solutions of different concentrations, useful energy can be obtained, which is called the salinity gradient energy (SGE). Reversible mixing of solutions back to the processes of separation of solutions, and desalination of water. Therefore, the methods for converting this energy are similar to the methods for separating solutions, but are directed in the opposite direction. To convert SGE into other forms of energy, primarily such as mechanical and electrical, it is proposed to use methods based on the following principles (Figure 1):

- osmotic, when the difference in osmotic pressure is used between solutions of different concentrations, separated by a semipermeable membrane;
- reverse electrodialysis, in which EMF occurs during the directional movement of ions with a charge of different signs through alternating anion and cation exchange membranes separating the solution of different concentrations.

Well, and a number of other ways.

![Figure 1. Installations for SGE conversion based on the following methods: a) osmotic; b) reverse electrodialysis.](image)

These two methods have already been implemented in practice in large industrial pilot plants. In 2009, Norway's state-owned energy company Statkraft unveiled the world's first osmotic power plant that generates power by mixing sea water with fresh water. In 2014, the Netherlands also rebuilt a larger and larger electrodialysis pilot plant called the Blue Energy RED-Stack Pilot Plant. The design capacity of the station is 50 kW. The installation is located on the Afsluitdijk dam, which separates the Zuiderzee from the North Sea, which has turned into a freshwater lake Eiselmeer. Previously, a small experimental back electrodialysis room was created and tested in our laboratory.

It was proposed to use this energy to transport icebergs across the ocean to arid regions of the Earth at the very beginning of research and development on these energy sources [2]. It is proposed to obtain fresh water with the constant melting of the iceberg by an osmotic installation. The second solution will be the surrounding seawater. These solutions must be fed to an osmotic unit to drive motors.

With our proposed use of transported fresh water to obtain energy for transportation, the first solution will be fresh water, and its amount is limited, and the second is sea water in an unlimited amount. In this case, we can use the expression we obtained earlier to calculate the power available at the mouths of rivers flowing into the seas [3, 4]:

\[ W = 0.2757TS\rho_1\Phi U, \]  

where \( U \) - fresh water flow rate, m\(^3\)/s, \( T \) - water temperature, °K, \( S \) - salinity of sea water, °/oo, \( \Phi \) - osmotic coefficient, \( \rho_1 \) - fresh water density, kg/m\(^3\).
Expression (1) allows us to estimate the maximum possible specific power of the EGS source equal to 2.45 MW per $1 \text{m}^3/\text{s}$ of fresh water flow at a salinity of 35 $^\circ\text{o}/\circ$ and a temperature of 10 $^\circ\text{C}$. The flow of water through the membrane depends on the difference between hydrostatic and osmotic pressure, the optimal value of which is found as follows. The expression for the value of the flow velocity through the membrane (m/s) has the following form [5]:

$$J = A(\pi - P),$$  

(2)

where $A$ is the constant of water flow through the membrane, m/(s·Pa), $\pi$ is the osmotic pressure of seawater, Pa, $P$ is the hydraulic pressure of seawater, Pa.

Then the power of the installation, W:

$$W = AsP(\pi - P),$$  

(3)

where $s$ is the membrane area, m$^2$.

Differentiating equation (3) with respect to $P$ and equating the derivative to zero, we obtain that the power will be maximum at $P = \pi/2$, while the efficiency of the process will decrease by 2 times. In addition, different losses when pumping solutions will reduce the real efficiency of the installation. The same is true for the efficiency of the reverse electrodialysis unit.

For the power supply of fresh water transport, osmotic and reverse dialysis units can be used, both separately and in combination, together. The advantage of an osmotic unit is that the mechanical energy to drive the propellers is obtained directly on the hydro turbine unit. And in a reverse electrodialysis unit, the electricity required to power the automation is directly obtained.

5. Transport of fresh water

Calculations have shown that the cost of building an underwater transport and docking devices for water intake and unloading will be approximately 1.2 mln. dollars. The power plant, when underwater delivery of 100,000 tons over a distance of 1,000 kilometers, will consume 8,000 tons of fresh water in 10 days. With a transportation cost of $1 \text{m}^3$ $\times$ 10, the payback period with all current costs will be 5 months.

The transport contains a cylindrical container made of elastic material for fresh water, a water intake and supply system, an engine, a power plant, a navigation and communication control unit with dispatch control and management. Transport has surface and underwater design options. In the case of only the surface version, the fresh water tank takes the shape of a cylinder when filled; when empty, it folds compactly like an accordion in diameter by internal cable winches attached to the front diametrical stiffness of the tank. The surface version is optimal for transportation over distances of more than 1500 km with the return to the loading point of several empty transports in a compact form by a cargo ship. In the case of the underwater version, instead of cable winches, the tank contains transverse elastic ties and a buoyancy device with a ballast of 3000 tons. The underwater option works at depth and surface, but returns for loading on its own. Ice conditions for the underwater option are not a hindrance. In both versions, a rigid structure of a streamlined shape is attached to the tank in front, in which there are four screw electric motors, an electrodialysis battery and an osmotic unit, a battery, water intake and return pumps, a control and communication unit. The transport is equipped with an automatic docking block for connecting to the structure at the points of water intake and return.

After manufacturing, the operability of all systems is checked and the programs are set up, and then it is brought into a compact transport state with a folded accordion water tank, without attaching the buoyancy ballast in the underwater version. One or several transports are loaded onto a semi-submersible dock ship and delivered to the loading point equipped with waste water intake devices. The dock ship is submerged; the transport floats up and is diverted from the ship to the water intake device. The transport is connected to a water intake device. The operator turns on the automatic control system and water is pumped into the transport tank. For surface transport, work with the dock ship ends before possible loading at the place of delivery of the cargo. After filling, the surface transport independently goes to the place of shipment. After partial filling and withdrawal in the surface position to a sufficient...
depth, the ballast of the buoyancy system is attached to the underwater transport by the dock. Further, according to a given program or at the command of the operator, the automatic transport control system is switched on, the underwater transport is docked with the fence device and is fully loaded. After filling, the underwater transport is disconnected from the fence device, in the above-water position it departs to an area with sufficient depth, submerges, and follows to a given point of the ocean, taking into account the depth and associated currents. To carry out such an independent transition, the transport uses, in an autonomous mode or at the command of the operator, a satellite communication system, a propulsion and steering complex, a motion control and stabilization system, a hydro acoustic navigation system and a hydro acoustic communication system.

Having reached the given point, taking into account all the given orientation parameters, the transport is docked with the unloading device. In the surface version, the container is pulled together by winch cables as it is unloaded into an accordion and, after unloading and disconnecting, the transport has a compact form for transportation to the loading place. The underwater version requires the remainder of fresh water to move independently to the loading point. After unloading, according to a given program, or as directed by a dispatcher, the underwater transport on the surface moves to a given area with sufficient depth submerges and moves to the loading point.

6. Conclusions
The proposed device for transporting fresh water by sea will effectively solve this problem without the use of additional energy sources.

7. References
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