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Autonomous Ecologically Safe Installation for Sea Water Desalination

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ABSTRACT
Urgency of the research: Urgency of the issue under discussion is caused by fresh water deficiency. Goal of the research: The goal is to develop a combined wind power unit for seawater desalination and a technology for the reverse osmosis concentrate process into product salts in the arid climate. Methods of the research: The leading method of the research is the testing of the wind power unit and the modeling of the reverse osmosis concentrate process. Results of the research: The article describes the main results of the literature analysis, represents the flowchart of the combined wind power unit for seawater desalination, the main results of the unit test, the flowchart of the basin management for the reverse osmosis concentrate recycling into product salts. Practical significance of the research: The further implementation of the project would allow to obtain drink water from seawater, as well as water for agriculture and product salts, which prevents reverse osmosis concentration discharge into the environment. The obtained results can be used to further improve water desalination equipment and to develop desalination plants powered by renewable energy sources; to modernize existing independent wind power units.

Keywords: fresh water, reverse osmosis, desalination, reverse osmosis concentrate, renewable energy sources, super capacitor

INTRODUCTION

Water resources on Earth are estimated at 1.386 billion km^3 and considered to be constant [1]. Theoretical sources of natural freshwater are estimated at 35 mln^3 km making 2.5% of the total Earth's water resources. Most natural freshwater is frozen in glaciers and perennial snow in Antarctica, Greenland, and locked in deep aquifers (up to 2 km). The human needs much more natural freshwater than provided by renewable sources, annually restored in the water cycle. Currently river runoff is considered to be the main source of natural fresh water the human needs. Thus, in spite of tremendous water resources on Earth, the amount, suitable for practical application (agriculture, industry, and household), is very limited and makes only 0.01% of water on Earth [1]. Mostly fresh water is in deficit in some regions due to two reasons: uneven distribution of freshwater on Earth, and civilization development.

The river runoff is distributed by continents and countries unevenly. About 70% of the annual volume of the Earth's renewable water resources is located in 10 countries, namely Brazil (8233 km^3), Russia (4498 km^3), Canada (3,300 km^3), US (3069 km^3), Indonesia (2838 km^3), China (2,739 km^3), Colombia (2132 km^3), Peru (1913 km^3), India (1908 km^3) and Congo (1283 km^3). The strongest deficit of freshwater is in Africa and the Middle East. Currently four out of every ten people on the planet live in regions with water scarcity. Two thirds of world population or 5.5 billion people are believed to live by 2025 in countries with water scarcity [2].

The water reserves remained unchanged for the last 5 thousand years of the civilization development. The population's well-being is improved due to the civilization development, increasing water use, namely consumption associated with human hygiene, and indirect water consumption associated with production of food

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and industrial goods. Indirect water consumption is associated with demand for man-made water. Currently, an average consumption of freshwater meets the following proportions: about 70% of surface and groundwater consumed in the world is used for irrigation of agricultural lands, 20% is used in industry, and 10% - for domestic use [2, 3]. The following tendency is observed: demand for water caused by increasing urbanization and industry is usually met by reducing water consumption for irrigation in agriculture. Further, the increase in demand for man-made water generates an increase in degraded fresh water irrevocably withdrawn from the freshwater circuit on Earth. The total flow of all rivers on the planet (renewable freshwater resources), estimated at about 24 million km^3 per year, is considered to be economically available fresh water [1]. So in 1900, the total consumption of fresh water in the world was estimated at 579 m^3, 331 km^3 of which was irretrievably lost, in 2000 - 3973 km^3, 2182 km^3 of which was irretrievably lost. Analysis of the dynamics of fresh water consumption from renewable resources for the last 100 years and freshwater quality degradation with the civilization development shows that in the period from 2025 to 2040, the global annual water consumption is comparable to the amount of renewable freshwater resources. Therefore, the Earth's civilization meets an issue of fresh water scarcity, which leads to development of effective methods of obtaining fresh water from the world's oceans. So the seawater desalination equipment market rapidly grows. For example, 4 mln m^2 per day was obtained in the world in 1990, in 2006 - 50 mln m^3 per day [4].

Currently, reverse osmosis and distillation are believed to be the main economically advantageous methods of obtaining freshwater from seawater, wherein the distillation focuses upon various methods of multistage distillation. The distillation method is the most used, and processes from 60 to 70% fresh water in the world, the remaining fresh water is prepared by reverse osmosis [4, 5]. Economic indicators, such as energy intensity, specific capital costs per unit, operating costs, demonstrate benefits of the reverse osmosis method. Thus the energy intensity in the reverse osmosis method is from 2.5 to 7.0 kWh /m^3 of fresh water, while as in the distillation method, this indicators from 12.5 to 24.0 kWh /m^3; in the reverse osmosis method, specific capital costs make $ 700 to 900 /($m^3 \cdot$ day), while as in the distillation method, this indicator is from $ 1200 to 1500/ ($m^3 \cdot$ day); specific operational costs make from 0.45 to 0.6 $ /m^3 of desalinated water; while as in the distillation method, this indicators between $ 0.75-0.85 /($m^3 \cdot$ day) (IWRA, 2010). For the period from 2001 to 2009, 9 reverse osmosis desalination plants were built with total capacity of 1.193 mln m^3 per day (Cyprus, USA, Israel, Australia, Algeria, and etc) [6].

Almost all existing water desalination plants throw resulting concentrate back into the sea, causing irreparable environmental damage, since many organisms are sensitive to salinity changes. Environmental damage is associated with salinization of the sea outfall. To fight this adverse phenomenon, a concentrate should be thrown to the open sea or to bottom areas. The main method of concentrate utilization is thermal evaporation [7]. This article attempts to present a technology to process concentrate into dry salts under arid climate conditions.

As for the Russian Federation, freshwater is relevant in the southern regions. Cheap energy sources, development of economically available technologies for desalination of marine and brackish water to produce fresh water could improve the situation with fresh water in these regions and provide the necessary conditions for creation of a self-developing territorial system [8, 9]. Experience shows that wind power plants are such an inexpensive source of energy. Application of autonomous wind energy units in desalination plants would provide with fresh water residential and industrial buildings, farms in areas with wind potential located near the sea or with subterranean sources of brackish water. This article describes one of the ways to solve the drinking water problem, namely the application of the combined wind power plant developed at the Bauman Moscow State Technical University. A goal was set while developing this plant – to obtain freshwater with minimum salt concentrate as wastewater, and in some cases with its full exception.

MATERIALS AND METHODS

Methods of Research

The following methods were used during the research: theoretical - analysis, comparison, synthesis, simulation, and empirical – experiment, simulation.

Experimental Base of the Research

An experimental model of the combined wind power unit served as an experimental base of the research.

Stages of Research

The combined wind power unit was studied for four stages: at the first stage, the current scientific and technological, regulatory and methodological literature on wind energy plants for desalination unit power, on methods of sea and brackish water desalination, water disinfection methods and salt concentrate disposal was analyzed; the problem was highlighted, the research goal and tasks were set, the research methods are defined, an experimental research was planned;

At the second stage, a combined wind power unit was synthesized, sketch design documentation was developed for an experimental sample of the combined wind power unit and the test bench, a research test program and methodology were developed;

At the third stage, a test bench and an experimental model of the combined wind power unit were made, the unit tests were conducted, test results were analyzed;

At the fourth stage, the process of obtaining dry salts from reverse osmosis concentrate was modeled.

RESULTS

Methods for Turning Seawater into Drinking Water and Product Salts

Based on the analysis of modern scientific, regulatory and methodical literature, methods of turning sea water into drinking water and product salts have been selected. The reverse osmosis desalination was chosen as a desalination method because it has such minimum economic indicators as energy intensity, specific capital costs, operating costs. Irradiation with high-level pulsed ultraviolet radiation of a continuous spectrum was chosen for desalinated water disinfection. This innovative technology has been developed by the Bauman MSTU scientific school. The first studies in pulse ultraviolet radiation of air and water purification technology were conducted in the late '80s and early'90s of the last century [10-13]. In recent years interest in pulse photochemical technologies is increased [14, 15]. Pulsed xenon lamps with high-current arc discharge at near-atmospheric pressure are used as pulsed ultraviolet radiation sources. The impact of strong pulsed radiation of the continuous spectrum causes, as a rule, irreversible photochemical damage, not eliminated by intracellular reparation mechanisms. Actual information shows [16, 17] that formation of pyrimidine dimers is not the only reason for cell inactivation by UV. Other types of damage include hydroxylation of nitrogenous bases, formation of DNA-protein bonds, chain breaks, and DNA denaturation, thus with increasing irradiation intensity the lesions become more significant [16]. The probability of double-stranded DNA breaks - damage unable to be repaired by most microorganisms - is known to significantly increase at high radiation intensities [18]. At high-intensity pulsed ultraviolet irradiation, a fundamentally different, atypical for low-intensity radiation, bioobject inactivation mechanism can be used along with the photochemical mechanism of the biocidal action - their thermal destruction forming as microorganism thermal explosion under intense ultraviolet radiation fluxes [19]. For evaporation of reverse osmosis concentrate in the arid climate, the air moisturizing based method was used. This property is widely used in drying processes [20].The basin method was used to obtain product salts under the arid climate conditions [21]. Independent operation of the combined wind energy unit is provided by a power supply module, using power storage based on super capacitors [22].

A Flowchart and Design of the Combined Wind Power Unit

Based on the analysis and the calculations, the sketch design documentation was developed, an experimental sample of the combined wind power unit was manufactured and tested, the flowchart is shown in **Figure 1**.

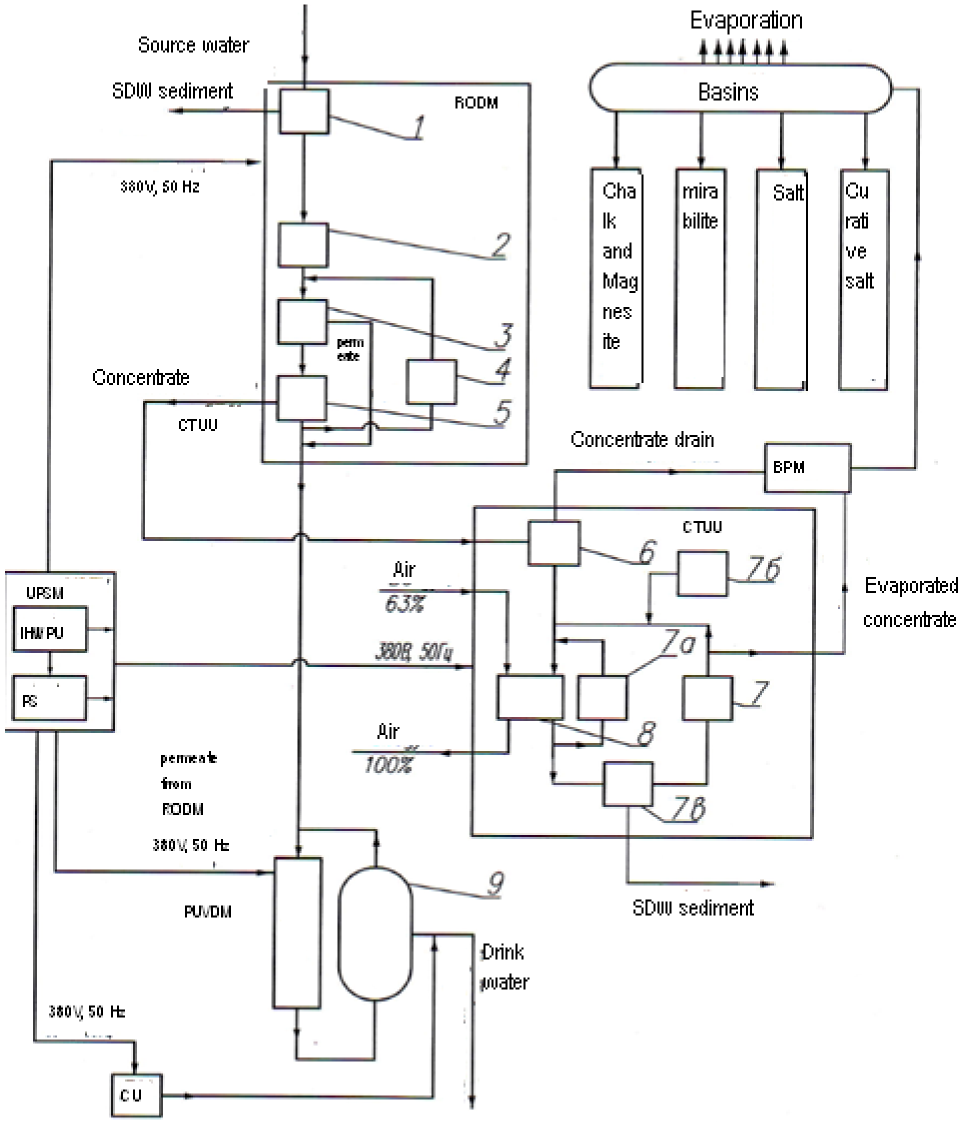

Figure 1. Flowchart of an experimental sample of the combined wind power unit:

IHWPU— independent hybrid wind power unit; CU — water conditioning unit; CTUU — concentrate thermal utilization unit; PUVDM — water pulsed ultraviolet disinfection module; RODM — module of reverse osmosis water desalination; UPSM — module of unit power supply; PS — power storage; SDW — solid domestic waste; BPM —brine purification module;

1 — source water pre-treatment unit; 2 — microfiltration unit; 3 — source water desalination unit; 4 — reverse osmosis filter washing unit; 5 — concentrate desalination unit; 6 —concentrate collector; 7 — intermediate capacity unit; 7a - evaporator washing unit; 7b - reagent dosing unit; 7c - bag filter; 8 — evaporator; 9 — storage reservoir.

A combined wind power unit is designed to produce drinking water and product salts from seawater. It consists of a reverse osmosis desalination module RODM, consisting of source water pre-treatment unit 1, microfiltration unit 2, source water desalination unit 3, reverse osmosis filter washing unit 4, concentrate desalination unit 5; the concentrate thermal utilization unit consisting of concentrate collector 6, intermediate capacity unit 7, evaporator washing unit 7a, reagent dosing unit 7b, bag filter 7c, evaporator 8; brine purification module BPM, basin system for product salt crystallization, module for pulsed ultraviolet disinfection PUVDM, storage reservoir 9, conditioning unit CU. The power of the combined wind power unit is provided by the UPSM power module, consisting of the independent hybrid wind power unit IHWPU and the power storage PS.

The elements of the reverse osmosis desalination module RODM are designed as follows: source water pre-treatment unit 1 is designed to clean source water from over 25 micron particles, microfiltration unit 2 to clean

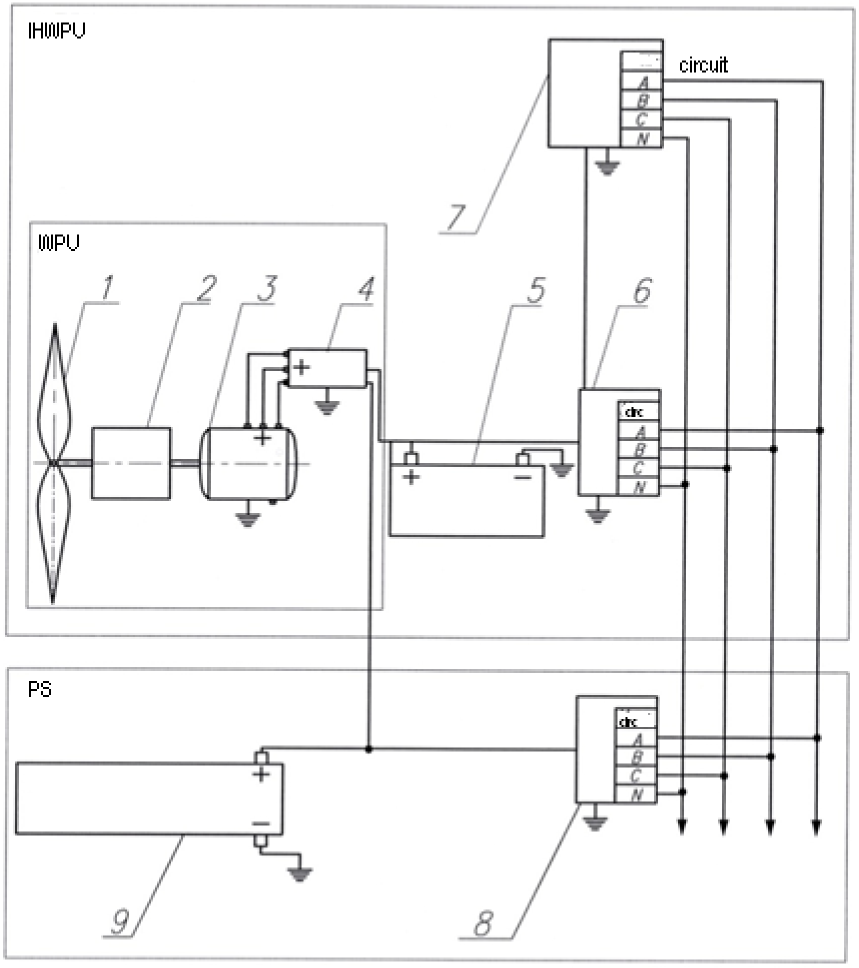

Figure 2. Flowchart of the unit power supply module:

UPSM — module power supply unit; IHWPU— independent hybrid wind power unit; WPU — wind power unit; PS — power storage;

1 - wind engine; 2 - power transmission system; 3 - electric generator; 4 - controller; 5 - storage battery; 6 - independent voltage inverter; 7 - diesel generator; 8 - charge-discharge device; 9 - super capacitors.

source water from over 5 micron particles, source water desalination unit 3 to separate source water into permeate and concentrate.

A flowchart of the unit power module is shown in **Figure 2**.

The independent hybrid wind power unit IHWPU consists of a wind power unit WPU, consisting of wind-powered engine 1, power transmission system 2, electric generator 3, controller 4, battery 5, independent voltage inverter 6, diesel generator 7. The power storage PS consists of charge-discharge device 8 and super capacitors 9.

Components of independent hybrid wind power unit IHWPU are designed as follows. Wind engine 1 to turn wind energy into mechanical energy of wind wheel rotation (kinetic energy of wind translation into kinetic energy of wind wheel rotation). Power transmission system 2 is used to transmit power from the wind wheels haft to the shaft of electric generator 3. Electric generator 3 is designed to convert kinetic energy of rotation into electrical energy. Controller 4 serves to convert alternating current into direct current and to control charging of battery 5 and super capacitors 9. Battery 5 is used to accumulate electric power and to supply power to all consumers in absent or insufficient power from other sources. Independent voltage inverter 6 is designed to convert direct current into alternating current, to control operation of diesel generator 7 and charging of battery 5 from diesel generator 7. Diesel generator 7 serves for backup power supply to the consumers. The energy storage ES is designed to smooth transient fluctuations in electricity generated by wind power units WPU.

The Principle of Operation of the Combined Wind Power Unit

Source water from wells or the sea is supplied to pre-treatment unit 1, where cleaned with pressure sand bed filters from fine impurities. Pressure sand bed filters remove over 25 micron particles. Next, the clarified water is supplied to microfiltration unit 2 to be purified via cartridge-type filter elements. Microfiltration unit 5 remove over 5 micron particles.

Then clarified and polished water flows into source water desalination unit 3. Reverse osmosis filters of source water desalination unit 3 separate with semi permeable membranes water into two streams, permeate (desalted water) and concentrate (high salt content water). The concentrate from source water desalination unit 3 flows into concentrate desalination unit 5. Reverse osmosis filters of concentrate desalination unit 5 with semi permeable membranes also separate the concentrate into two flows: permeate and concentrate.

Permeate from source water desalination unit 3 and concentrate desalination unit 5 is supplied into the water pulsed UV disinfection module (PUVDM) where the water is irradiated with high-intensity pulsed UV radiation of a continuous spectrum. Such impact on the water is caused usually by irreversible photochemical damage to vital structures of biological organisms, not removable by intracellular repair mechanisms, thus achieving high efficiency water disinfection as for the most stable (spore) form of microorganisms and viruses. The effectiveness of water disinfection is not less than 99.99%. The radiation source is a pulsed xenon lamp. In contrast to conventional UV water disinfection with mercury lamps, the PUVDM operates in a fully automatic mode, providing a guaranteed antimicrobial barrier. The novelty of the solutions, applied in the PUVDM, protected by the utility model patent [23].

The water from the PUVD flows into storage reservoir 9. The PUVDM and storage reservoir 9 have a ring main providing continuous disinfection of the water in reservoir 9 in case of long-term stop of the reverse osmosis desalination module (RODM).

The water from storage reservoir 9 is supplied to the consumers. At exit from the reservoir behind the ring main, the water is conditioned, i.e. the disinfected water from the water conditioning unit CU is diluted with "Severyanka" saline to enrich the water in nutrients required for normal human activity. The saline is injected via an automatic dosing pump. Upon conditioning, the water meets the required quality requirements, namely SanPin 2.1.4.1074-01 [23] and is supplied to the consumers. The water is conditioned only in case of a water analysis by the consumer.

The concentrate from concentrate desalination unit 5 is supplied to the concentrate thermal utilization unit (CTUU) where collected in concentrate collector 6. From concentrate collector 6, the concentrates supplied by the centrifugal pump to evaporator 8 and for recycling. To evaporate the salt concentrate, a fan evaporative cooling tower GRD 115-M is used.

Intermediate capacity unit 7 and evaporator 8 form a circulation loop for a salt concentrate circulation between evaporator 8 and intermediate capacity unit 7 with circulation pumps of total capacity of 130 m^3 /h. To evaporate the reverse osmosis concentrate, an ambient heat is used determined by the temperature difference of wet and dry thermometers. This method of the water evaporation from the reverse osmosis concentrate is environmentally safe and in most cases does not require thermal energy from outside sources. To eliminate any deposits on the flow of evaporator 8, the evaporator maintenance schedule provides for washing of evaporator 8 by evaporator washing unit 7a. To adjust rewater acidity in the circulation loop to reduce the probability of carbonate deposits, reagent dosing unit 7b provides by dosing some acid (hydrochloric or sulfuric acid) into the circulation loop. Bag filter 7c is installed to remove some salt sludge from the circulating concentrate in the circulation loop.

Upon reaching a predetermined indicator of the salt concentrate, the evaporated concentrate is supplied to the brine purification unit (BPM). Also, the reverse osmosis concentrate, discharged before evaporation, is supplied to the BPM. The mixture of the reverse osmosis concentrate discharged from the CTUU before the evaporator and the evaporated concentrate discharged from the CTUU circulation ring, hereinafter referred to as brine. To process the brine, the arid climate properties are used, namely the climate with strong evaporation forces, dry climate, strong winds, little precipitation. Thus, the technology of solar salt production from seawater by the basin method was taken as a base [21, 23]. The brine processing basin method is based on solar energy used to evaporate water and natural cold to crystallize salts. Most of seawater salts (by weight) have the pronounced temperature dependence of the solubility from minus 20 to plus 20°C, therefore, seawater processing in the Southern regions of Russia is believed to be economically advantageous.

The basin management composition and size was estimated from the following considerations. The CWPU waste water recycling assumes to receive chalk, magnesite, mirabilite, sodium chloride, and master brine. Chalk and magnesite are planned to use as raw materials for building materials, mirabilite- as a raw material for medicine, salt - as a finished product for consumption. Master brine enriched in potassium and other elements, as shown below, is intended to pack for therapeutic use. The number of basins is determined by the composition of elements obtained from wastewater. Dimensions of basins with increased brine concentration due to evaporation under the

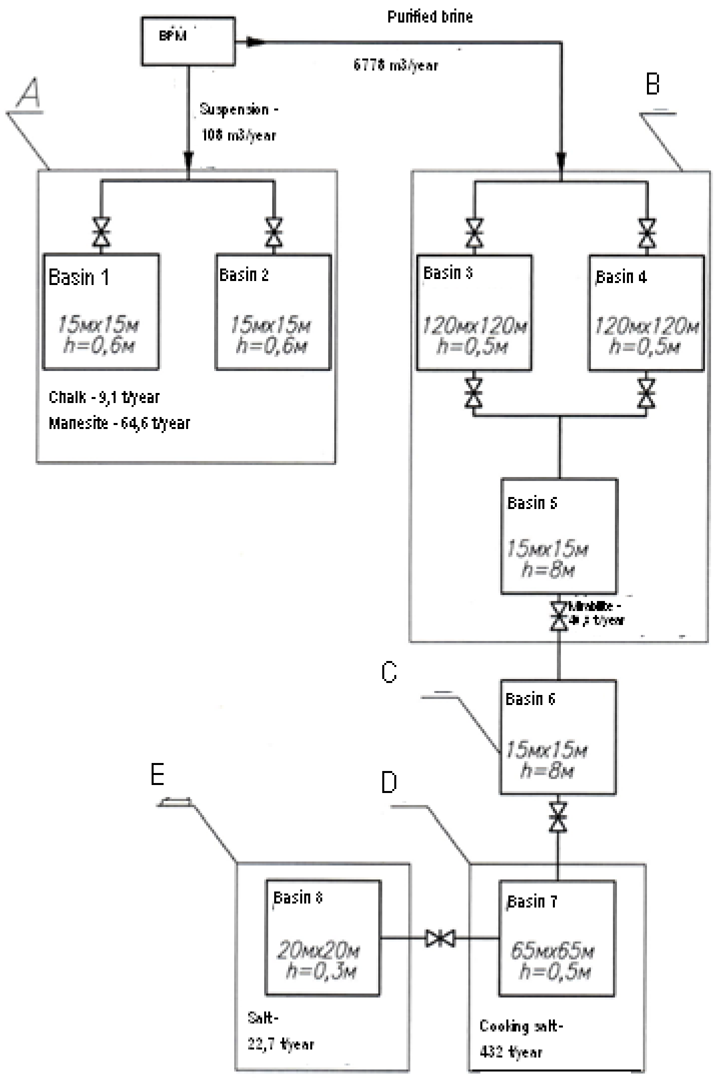

Figure 3. Flowchart of the basin management:

BPM— brine purification module; A — chalk and magnesite dehydratation; B— preparation of mirabilite brine and settling; C— spare basin; D— preparation of salt brine and settling; E— basin with master brine.

environment were assumed that the sediment would be thick of 40 to 60 mm and the brine layer level would reach 400 mm. A flowchart of the basin management is shown in **Figure 3**.

The brine from the CTUU is suggested to be purified from sulfates and chlorides using soda ash in the brine purification module (BPM) [24, 25]. The brine is purified in four stages:

- preparation of soda solution;
- mixing reagents with brine;
- chemical reactions (direct brine purification from impurities);
- clarification of purified brine.

To simplify the brine separation into fractions by the basin method, the wastewater treatment cycle is proposed to start from 01 January. During the year, the suspension is discharged into basin 1. At the same time the clarified brine is discharged into basin 3. Next year, the suspension is discharged into basin 2, the clarified brine –into basin 4. From April to September, the water in basin 1 evaporates, a 120 mm layer of mirabilite and chalk mixture remains on the bottom, thus chalk output is estimated at 9.1 tons, and magnesite - 64.5 tons.

From April to September, the clarified brine evaporates in basin 3. The initial brine volume is to be 6778 m^3. By the end of the season, the brine concentration reaches 260 g / l, and its volume is to be 469 m^3. Before cold weather arrives, the brine is to be poured into a smaller basin, namely in basin 5, otherwise mirabilite thickness is to be about 2 mm. In basin 5, mirabilite will be settled. A mirabilite thickness is to be 120 mm. Expected mirabilite

Table 1. Expected composition of the brine

Chemical compound	Name	Annual output, kg /year	Mass fractionin%
NaCl	Sodium chloride	22721	60.31
$K_2 SO_4$	Potassium sulfate	12461	33.07
$K_2 CO_3$ and others	Potash and other substances	2493	6.62
	Total:	37675	100.00

outcome is 27.4 t / year. In the autumn, upon mirabilite settling, the brine should be poured into basin 6, to be stored until next April. In late May, the brine from spare basin 6 would fill basin 7 to the level of 160 millimeters, which corresponds to 676 m^3 of brine. While the water from the brine and salt settling is evaporating, the brine from spare basin 6is added to sedimentary basin 7. By the end of the season, the salt thickness is expected to be from 40 to 50 mm. The resulting brine drains from basin 7 into basin 8. The further technology of salt production corresponds to the traditional one, namely salt break-up, piling to clean from master brine, packaging and delivery to the customer.

The expected composition of the brine in basin 8 is shown in **Table 1**.

As for medicine purpose, brine is valuable because of high potassium and low sodium content, so it is close to the Dead Sea salt by composition and curative properties. Brine in a liquid form can be poured into containers from 5 to 10 liters and used for medicinal baths or left until the following season, having vaporized water and prepacked salt to be used in medicine.

An independent operation mode of the combined wind power unit is provided by the UPSM, which consists of the IHWPU and ES. The independent hybrid wind power unit includes a wind park. The UPSM supplies electricity to all modules of the unit. **Figure 2** shows a flowchart of the UPSM. The UPSM operation principle is as follows. At wind flow clashing to wind engine wheel 1, its shaft starts to rotate and transfer power to power transmission system 2. Here rotation speed of the output shaft of power transmission system 2 is increased coordinating rotation of wind engine 1 and electric generator 3. Electric generator 3 converts mechanical energy of wind engine 1 to three-phase electric current energy.

The consumers (RODM, CTUU, PUVDM, BC, MPAs) are powered by the WPU. If power generated by electric generator 3 and the energy from battery 5 would be insufficient to power the consumers, independentvoltageinverter6 switches diesel generator 7 to power the consumers.

The WPU operation experience shows that wind energy in transient fluctuations can reach 80% of the fluctuation-free wind energy. Electricity in wind fluctuations would increase the efficiency of newly designed and existing WPUs. Therefore, the UPSM is equipped with the power storage and, controller 4 is refined to create a channel for power per capacitors 9. The PS smoothes transient power fluctuations generated by the WPU and accumulates the energy from transient fluctuations in super capacitors 9, followed by power supply to the circuit without transient fluctuations.

The Methodology of the Research Tests

An actuating medium to test the unit is model source water (MSW) simulating an average water salinity and annual temperature of the Black Sea and the Sea of Azov in the Crimean water area.

The unit tests are conducted under normal climatic conditions:

- ambient temperature (25 ± 10)°C;

- relative humidity (50 ± 25)%;

- atmospheric pressure (96 ± 10) kPa.

Before tests, the MSW solution of required salt content and temperature is to be prepared.

The MSW parameters:

- MSW temperature: from + 2 to + 28°C;

- MSW pressure: from 355 to 410 m;

- MSW consumption: 5.0 to 2.7 m^3 /h.

The stand flowchart is shown in **Figure 4.**

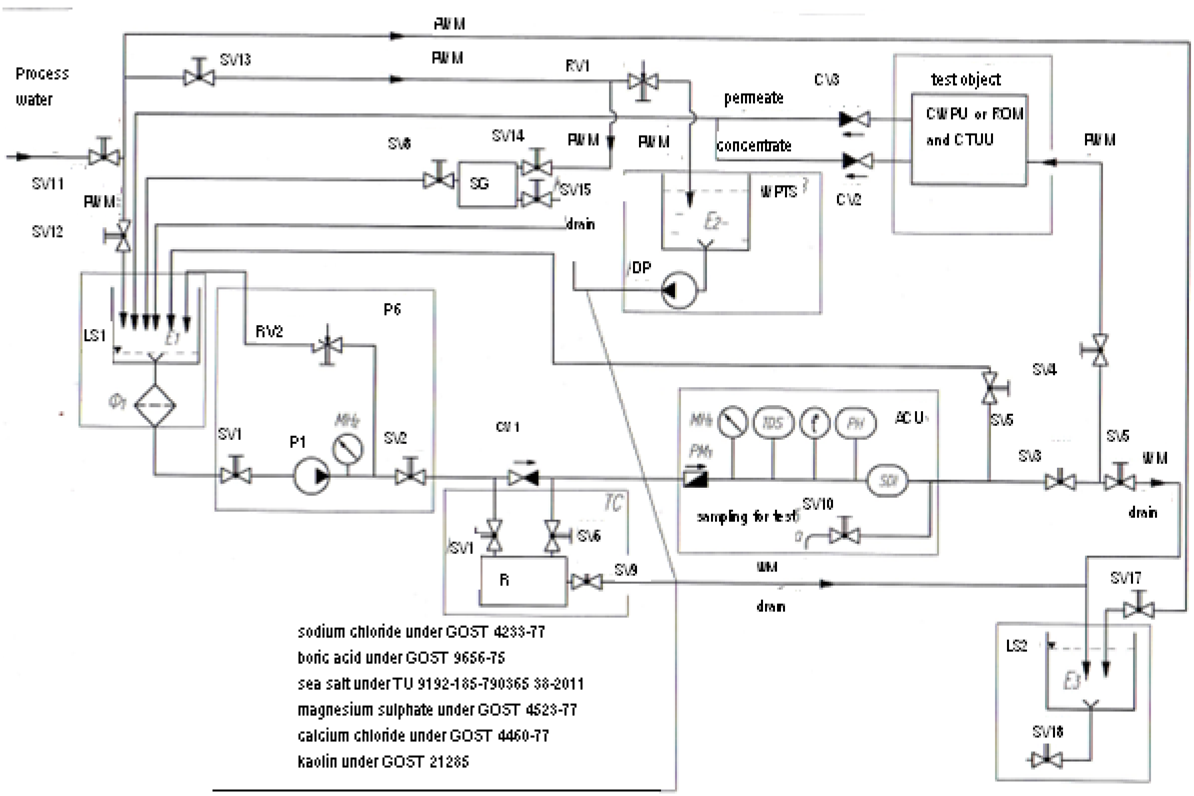

Figure 4. Hydraulic circuit of the test bench:

PU — pump unit; WPTS — water pre-treatment system; ACU — analysis and control unit; SG — steam generator; R — refrigerator; TS — thermostat; C1-C3 - capacities; SV1-SV18— manual shut-off valve; P1 — centrifugal pump; MN1 and MN2 — manometers; RV1 and RV2 — hand adjustable valve (membrane valve); CV1-CV3 — check valve; DP — dosing pump; LS1 and LS2 — level sensors; FM — flowmeter; TDS — brine gauge; T — thermometer; PH — pH value meter; SDI — turbidimeter; PWM - process water main; WM – waste main; CWPU - combined wind power unit; ROM - reverse osmosis module; CTUU - concentrate flow heat utilization.

Preparation of the test bench actuating medium (MSW)

Open valve SV11, the process water comes to the process water main. Open valve SV12 and fill capacity C1 with the process water to a volume of 3.9 $m^{3.}$ Close valve SV12.

Fully open the RV2-regulated valve, valve SV1, switch pump P1. The process water is pumped through the bypass pipe. Add 90% of required preformed components to capacity C1.

Open valve SV13 and the RV1-regulated valve. Fill capacity C2 with the process water to a level of 80 liters. Close valve SV13 and the RV1-regulated valve. Switch the mixer and add the required amount of ingredients to create a concentrate. Ingredients solubility should be considered to avoid precipitation of the ingredients during their transportation to capacity C1.

Open valves SV5, SV2 and close the RV2-regulated valve so that model source water comes to capacity C1 through the ACU. The model source water circulates in a closed circuit: capacity E1, the analysis and control unit ACU, capacity E1. Basing on values of the analysis and control unit, determine the MSW physical parameters. Take a MSW sample for laboratory tests. If necessary, add the right amount of concentrate with the dosing pump DP to obtain the required quality of MSW. Since the MSW composition corresponds to predetermined, the stand actuating medium is prepared for the test.

To start pump P1, switch power on the remote control of the QF2engine protection, then pressing "P1" button on the remote control, switch pump P1. Thus, the controller monitors the level sensor in capacity C1 and, in case of incorrect switching (solutions over), blocks the button and switches the "BLOCK" HL2 indicator. Further operation is possible upon removing the blocking reasons.

Desalination module tests suggest them to be conducted in source water, simulating physical and chemical indicators of water of the Black and Azov Seas. So, the desalination module tests provide for the model solution working temperature from +2 to +28°C, which corresponds to temperature fluctuations of coastal water of Russian areas of these seas.

Proceed to the next step: prepare the MSW solution of required salinity and temperature; switch the refrigerator R and open valves SV6 and SV7. The actuating medium is circulated in a closed loop: capacity C1, the R, the ACU, capacity C1. Upon reaching the desired temperature of MSW, the stand actuating medium is prepared for the test.

The next step is to prepare the MSW solution of required salinity and temperature. So switch the steam generator SG, open valve SV8 and feed the steam to capacity C1; open valvesSV14 and SV13 to feed process water to the steam generator boiler. While the MSW is heated, about 100 liters of water come into the reactor, therefore it is necessary to control the MSW composition and if required add a concentrate with the dosing pump DP to capacity C1. Upon reaching the desired MSW temperature, the stand actuating medium is prepared for the test.

Then the objects should be tested without heating and cooling MSW. Upon reaching the physical MSW parameters, open valves SV3 and SV4, close valve SV5 and supply the MSW to the test object. The resulting permeate and concentrate of the test object come to capacity C1. Set a bypass pipe with the RV2-regulated valve for continuous agitation of the MSW incapacity E1. Monitor the MSW parameters with the ACU values during the object tests. If necessary add a concentrate or process water to capacity C1. At the end of the test, open valve SV16 and drain the MSW into capacity C3 for wastes. Rinse capacities C1, C2 and mains with process water.

The subsequent steps should be as follows:

1) Object test at MSW cooling. Perform all stages of the object test without heating and cooling MSW. Periodically switch the R off according to the refrigerator operation instructions.
2) Object test at MSW heating. Perform all stages of the object test without heating and cooling MSW. Control a water level in the boiler, when necessary, add process water to the boiler.
3) Drain wastes from waste capacity E3. Content of capacity E3 represents MSW with high content of ingredients. Upon a waste content analysis, issue a certificate to determine how to mix with the process water in order to drain waste into a sewer. If chemically active substances are used for washing the capacities and mains, the waste should be disposed according to the chemically active substance application instruction.

The Results of Research Tests

The PECWPU tests were conducted in model source water (salt brine) under the following conditions:

– source water temperature varied from + 2 to + 28°C;

– source water pressure varied from 370 to 420 m;

– source water flow varied from 3.5 to 4.5 m^3 /h;

– salt content of 18 g / l.

During the conducted tests, it was found:

– conversion degree (hydraulic efficiency) varied from 45 to 61%;

– permeate flow varied from 1.8 to 2.5 m^3 /h;

– permeate salinity varied from 57 to 257 mg / l.

The dependence of specific energy consumption by the RODM at different temperatures of source water is shown in **Figure 5**.

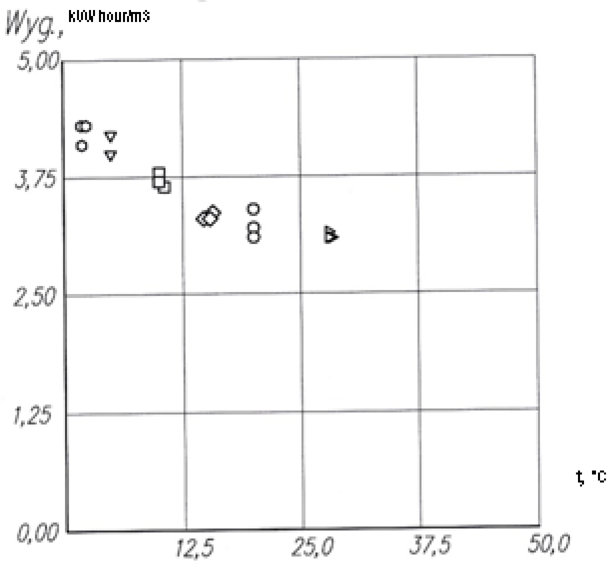

Figure 5. Dependence of specific energy consumption by the RODM (W sp, KWh /m$^{3)}$ on source water temperature (t, °C)

Table 2. Technical characteristics of the PECWPU

Indicator	Measurement unit	Value
Performance by source water (the Black Seawater).	m^3 / day	88.3
Source water temperature.	°C	+ 20
Source water salinity.	g / l	18.0
Performance by desalinated water.	m^3 / day	50.0
Desalted water salinity.	Mg / l	168.0
Water supply guarantee.	%	98.0
Fresh water disinfection effectiveness	%	99.99
Reverse osmosis concentrate salinity.	g / l	44.7
Reverse osmosis evaporated concentrate salinity.	g / l	101.4
Solar salt output (NaCl).	t / year	432.0
Chalk and magnesite mixture output ($CaCO_3$ + $MgCO_3$).	t / year	73.7
Mirabilite output (Na_2 SO4 · 10H2O).	t / year	40.8
Healing brine output.	t / year	22.7
Power consumption.	KW	22.6
Autonomous power from 10 OCA-3000 wind power units.	KW	30.0
Solid domestic waste output (inert).	kg / year	580
Wastewater output (inert).	m^3 / year	1.0

Figure 6 shows that the RODM specific energy consumption substantially increases with decreasing source water temperature. Thus, at changing the source water temperature from +28 to +2°C, the RODM specific energy consumption varies from 3.1 to 4.3 kWh/m^{3,} which corresponds to 39% increase in the RODM energy consumption. Physically, this is explained by decreasing water molecule mobility at reducing the source water temperature, and thereby water viscosity increases. As for specific energy consumption for desalination by reverse osmosis, compared to other methods, this level is quite low. For example, heat consumption for preparation of 1 kg of fresh water in a single-stage distillation desalination unit is about 2400 kJ (or 667 kWh/m^3), in the multistage distillation desalination unit is from 250 to 300 kJ (or 70 to 83 kWh h/m^3) [26]. According to the experimental data shown in **Figure 6**, the power consumption for desalination of 1 kg of source water makes from 11.2 to 15.5 kJ. Such low power consumption is provided by no phase transition of water in reverse osmosis desalination.

The PECWPU research tests showed no significant deviations from the project technical assignment.

The PECWPU specification is made according to the research results presented in **Table 2**.

DISCUSSIONS

The literature analysis allowed to come to the conclusion that still the problem of fresh water deficit has been neglected. The issue studying shows insufficient specific researches, dedicated to combined wind power units for seawater desalination; and to develop technology for reverse osmosis concentrate recycling to product salts in the arid climate is considered to be an innovative project.

The article contains the flowchart of the combined wind power unit for seawater desalination, and also the flowchart of the basin management for the reverse osmosis concentrate recycling to product salts. The further process of reverse osmosis concentrate, economically profitable, is offered to obtain product salts to be used in individual baths and as a raw material for medicine and cosmetics; as well as to produce useful materials for construction and cooking salt.

Main results of the unit tests show that the further reverse osmosis concentrate process minimizes the total waste flow, which is 1.76×10^{-3} % of the total flow of reverse osmosis concentrate (1 m^3 /year - wastewater from reverse osmosis filter washing), solid domestic waste, which is 1.02×10^{-3} % of the total flow of reverse osmosis concentrate (580 kg /year –waste quartz sand from pressure filters) and increases the project commercial attractiveness. Wastewater and solid domestic wastes are inert substances, which should increase the project environmental attractiveness, as well as justify the further development of this research.

The results demonstrate that, despite the experimental sample feasibility, the further researches are required to develop modifications to use water desalination units of this type worldwide. The study of this issue would contribute to development of tailored strategies aimed at reducing economic costs for independent unit commissioning, as well as development of basic modifications for different groups of the population and reducing the environmental burden of salt concentrate as waste, and in some cases its full elimination.

CONCLUSION

This project will eliminate discharge of highly mineralized concentrates, which may significantly damage the environment. Application of the pulsed UV water disinfection module for water irradiation with high-intensity pulsed ultraviolet continuous spectrum radiation increased the water disinfection efficiency and reliability comparing to conventional methods, and for the first time to fully automate the fresh water producing process. The use of super capacitor-based energy storage and the controller revision allowed to use the energy from wind fluctuations. It provides the opportunity to continue modifications of existing independent wind power units to increase their power at the same wind load. The tests of an experimental sample of the combined wind power unit have been conducted. The specification of the 50 m^3/day seawater desalination unit has been presented.

The content of this article can be useful for constructors at designing new desalination units, and for engineers in upgrading the existing ones.

During the research, new questions and problems appeared to be solved. The researches on the unit development should be continued.

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