Floating «green» desalination plants

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Annotation

Floating "green" desalination plat, based on direct wave energy conversion to water pressure, required for Reversed Osmosis Desalination (ROD) is proposed and described. ROD could have traditional basic configuration, or equipped with additional energy recovery system. Proposed Wave Energy Converters (WEC) transform energy directly into intensely pressed water required to ROD. All equipment located on an autonomous pontoon, which produces desalinates water directly from sea waves' energy. Proposal has great international potential.

Description below reflects two proposals – first is based on Water Filled Floats (WFF), the second one - on a Floating Oscillating Water Column (FOWC).

The status quo

For many years, scientific, governmental and public organizations in Israel have been dealing with water balance issues in Israel. Many projects have been proposed and implemented aimed at improving water supply in Israel, and many are currently under consideration. Some of them suggest, for example, building islands in the Mediterranean Sea to house desalination plants and a power station for them. Just currently, government agencies are considering adding desalinated water to the Sea of Galilee.[1]

Some years without rain and a continuous increase in water consumption - pushing the country to extend desalinated water production up to 700 million m^3 per year. But even this is not enough, and new proposals of the desalination plants are under way. For reverse osmosis desalination plants (RODP), coastal territories are required as well as electric power. It is about 5 ... 8 kWh per cubic meter of produced water and price determines mainly by electricity cost. The main consumer of electricity in RODP is high pressure pumps, which supply water at a pressure of 5 …7 MPa to the RO filters.

Each 1 m^3 of desalinated water, require about 2 m^3 of sea water to be pumped to the filters with pressure of 6 MPa. So - production of $1m^3$ of desalinated water with pump's efficiency Eff=0.8 and 6 MPa pressure - required energy equal to $E=\Delta V*Pr/Eff=2m^3*6MPa/0.8=15MJoule$. For RODP with $1m^3$/sec (31.5 million m^3 per year) productivity we need 15MW power. Energy required just by 6 MPa pump for water production is equal to 15MJ/ m^3=4.17 kWh/m^3. Actual required energy will be significantly higher (and could be up to 8 kWh/m^3) due to clogged filters and other energy consumers. That is why some desalination plants are often combined with the thermal hydrocarbon power plants.

Renewable ("green") energy sources – do not need hydrocarbon fuel and do not pollute the atmosphere. Solar and wind power plants are developing successfully, the cost of the energy they produce is continuously decreasing. Wave Power Converters (WPC) are very promising, but existing experimental WPC are still pretty far from the large-scale application.

In the book "Energy problems of the present and the possibilities of the future" V.G. Rodionov reviewed many different wave energy projects and discussed their problems [2].

Below we consider new WPC approaches which are not described in the literature. The closest analog is Smith's float system - fig.15.7, p. 235 in [2].

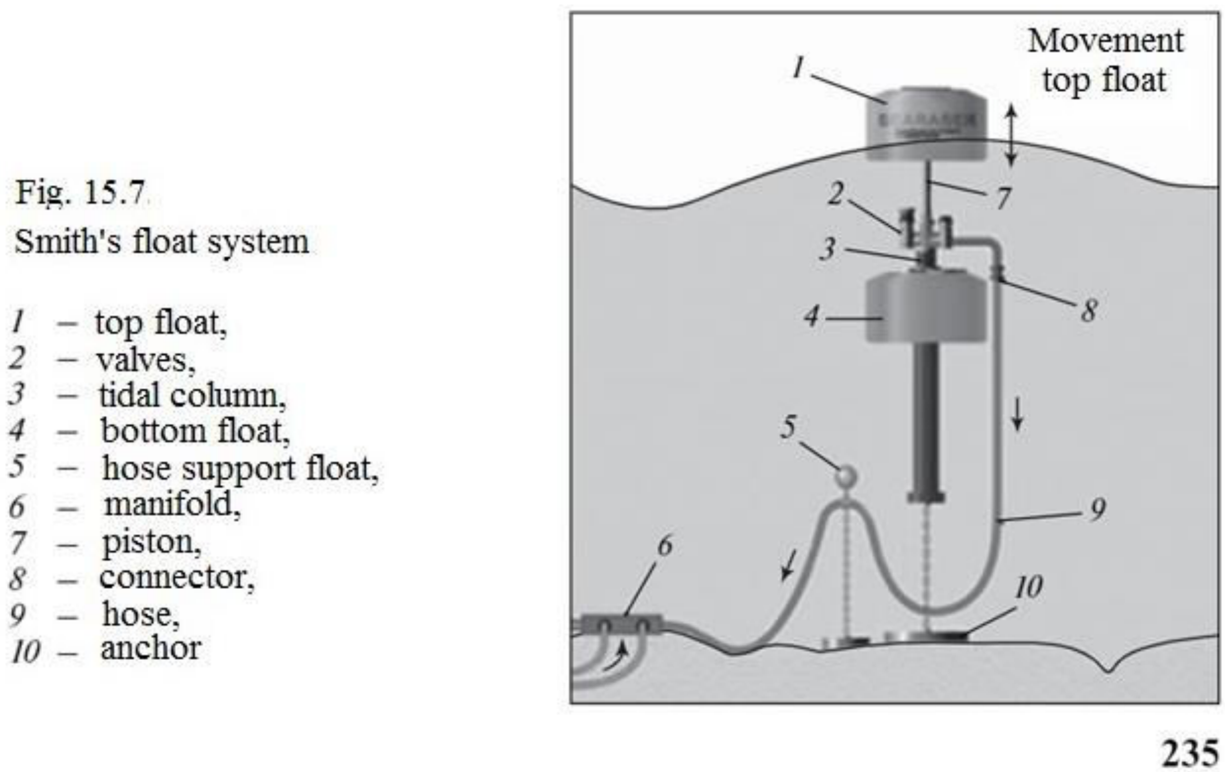


Fig. 1 Smith Float System Generator

The objectives of the proposals

- To install floating “green” desalination plants on the Mediterranean.

- To produce substantial amount of drinking water for the needs of Israel.

- To reduce storm waves’ destructive effects on the coasts.

- To offer floating “green” desalination plants internationally.

Features of the offer

Two described below proposal have many common features:

- They both are based on direct wave energy conversion into highly pressed water required for ROD.
- They both using Reverse Osmosis as desalination process.
- For both of them all equipment is located on the deck of floating pontoons and not under water (like Smith's Float System Generator (Figs. 1.)
- In both proposals - desalinated water flows ashore through a water conduit.

Still there are significant differences between two: first proposal is based on Water Filled Floats (WFF), while the second one - on a Floating Oscillating Water Column (FOWC).

Description of the desalination plant based on the 1st proposal
(Water Filled Floats - WFF)

All equipment is mounted on the large rectangular pontoon. 400 Water Filled Floats (WFF) with pumps are located along pontoon's two long sides. WFFs are floating and swinging on the waves and activating pumps through the levers. Pumps supply sea water under the necessary high pressure directly to the RO filters.

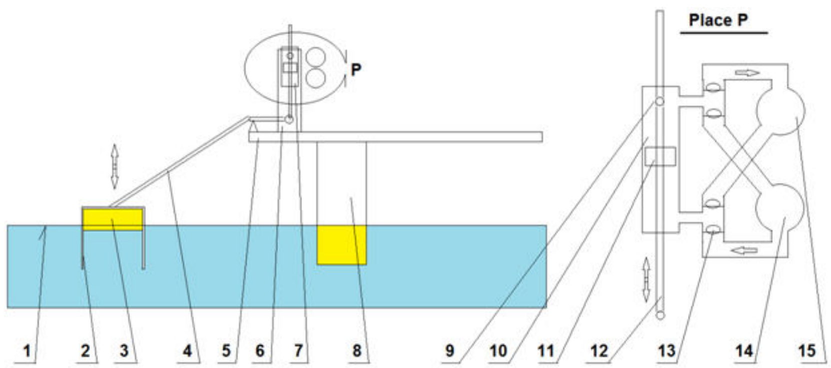


Fig. 2. Layout of the equipment on the pontoon

Figure 2 shows the layout of the equipment. Sea level 1, a hollow float 2 floats and sways on the sea surface, inside of hollow float there is a light filler 3. The hollow float is connected by a lever 4 to the rod 12, on which we have a piston 11. The piston moves in the cylinder 7, 10, on the cylinder we have a pin 9 on which the cylinder is mounted on the rack 6. The rack 6 and the fulcrum of the lever 4 are installed on the deck 5 of the pontoon. The outputs of the cylinders are connected through check valves 13 to the low pressure pipe 14 and to the high pressure pipe 15. In the pipeline 14, seawater comes from a desalination plant, after all stages of preliminary water treatment. From the pipeline 15, water flows directly into the RO filter.

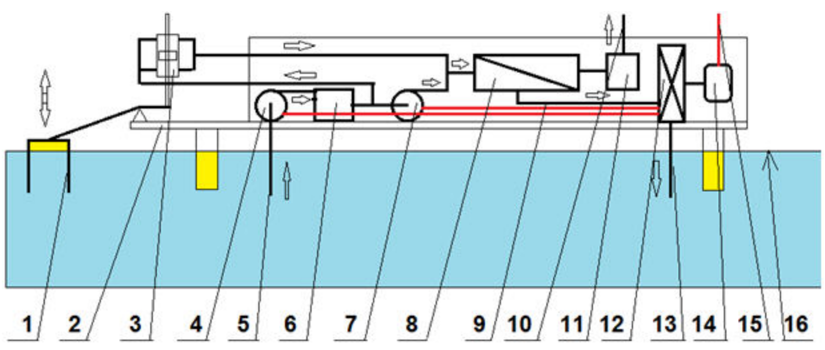


Fig. 3. Connection diagram of the desalination plant with pistons and floats

Designations in the diagram Fig. 3: 1 - hollow float, 2 - pontoon, 3 - wave high pressure piston pump, 4 - low pressure booster pump, 5 - suction line, 6 - water pre-treatment equipment, 7 - high pressure electric pump, 8 - RO filters, 9 - high pressure concentrate line, 10 - desalinated water outlet line, 11 - equipment for mineralization and drinking water additional processing, 12 - high pressure turbine, 13 - concentrate drain line, 14 - electric generator, 15 - exit line electricity, 16 - sea level.

The scheme of the proposed desalination plant is fully consistent with the industrial desalination plant, which is supplemented by our wave pump 3. The piston of the pump 3 receives energy from the floats 1, which moves up and down by the waves. An electric booster pump 5 along the suction line 4 receives seawater and supplies it to equipment 6 for the source water preliminary processing. Prepared water enters the high-pressure wave piston pump 3 and the high-pressure electric pump 7. Water from pumps 3 and 7 enters at a pressure of 5…7 MPa into RO filters 8. Desalinated water enters the equipment 11 for the drinking water mineralization and additional processing. Line 10 is the drinking water output.

Concentrate leaves the filter through line 9 and has almost full initial pressure. The volume of concentrate is approximately equal to the volume of desalinated water, so and the energy. Half of the pump's energy is spent for pushing water through the filter, while another half remains in the concentrate. This second half is usually wasted, unless recuperated with additional equipment. Energy recovery is based on directing the concentrate through a turbine 11, which activates electric generator 13. After the turbine, the concentrate is discharged into the sea via line 12. An electric generator feeds electric pumps 4 and 7, as well as other equipment on line 14.

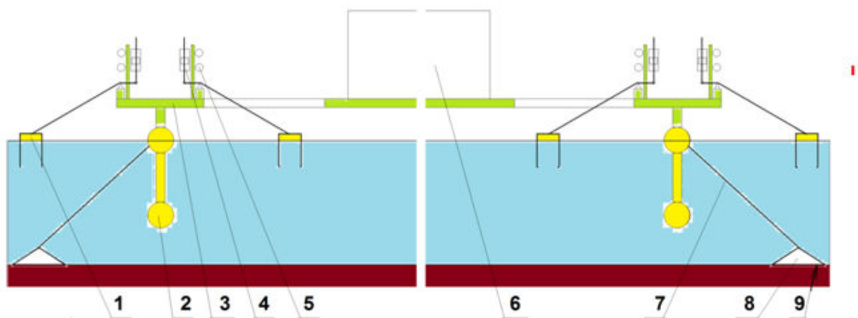


Fig. 4. Layout of equipment on the pontoon.

Designations in the diagram Fig. 4: 1 - a hollow float, 2 - a floating power pontoon truss, 3 - pontoon deck, 4 - high-pressure wave piston pump, 5 - pipelines, 6 - desalination facilities, supplies warehouses and a cabin for staff, 7 - anchor chain, 8 - anchor, 9 - bottom of the sea.

The floating power pontoon truss is made of steel pipes (see Fig. 7). Pipes are filled with lightweight material, for example, foamed polyethylene to obtain buoyancy of the pontoon. The steel truss is strong enough to withstand storm loads.

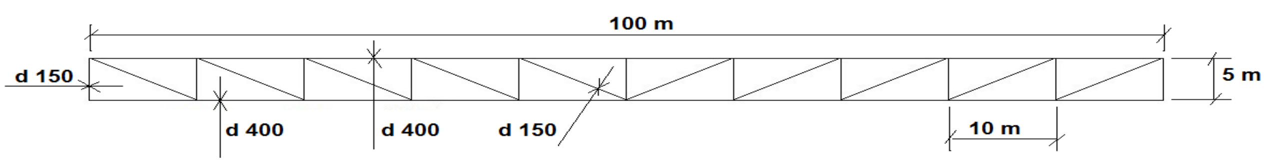


Fig. 5. Strong floating pontoon trusses.

Energy performance:

Statistics of the wave's heights and periods at the Israel Mediterranean cost shows, that most probable waves have heights from 0.8m to 2m and periods around 4sec, which is in a good agreement with the empirical results, described in [4].

Calculation for the wave height of Hw = 0.8 m.

Pump supplies source water at a pressure of P=5 MPa. Assuming that float has an area of 1 m^2 and 1250 N buoyancy (when submerged)- the same buoyancy force of 1250 N will be applied to the lever 4 (Fig. 2) when wave increasing and moves the float up. The lever arm ratio is 1/10, so the force on the pump's rod is B = 12500 N. To create pressure of P=5 MPa the area of the piston must be S = B / P = 25 cm^2.

When wave is lowering down - the float can not follow right away (because the piston is closed by check valves), but begins going down only after wave level decreases further and reaches dH=0.125 m below the water in the float. At that moment volume of the water in the float above the wave level reaches 125lit=dH*S, and with 125 kg mass – creates 1250 N force on the lever and 12500 N force on the piston, which compensates P=5 MPa pressure on the check valve.

When wave continues down – the float follows keeping dH=0.125 m. But when wave reaches it's minimum and starts increasing – the float stops and waits until being submerged by the growing wave, which creates buoyancy force capable to open another check valve. It happens when wave's level is 0.125 m above water in the float (dH=-0.125m). Therefore, the course of the floats is H1=Hw - 2*0.125 m=0.55 m. The mass of water in a hollow float is equal to b = 125 kg. It produces energy A = b * H1. This energy through the lever and piston is transferred to the water A = P * s * H1 / 10 = 690 Nm.

Water consumption per cycle when the piston moves down is equal to:
Q_wave_rise = c * (H1/10) = $25 * 10^{-4} * (0.55/10) = 0.138 * 10^{-3}$ m^3 =138 ml/cycle.
The float and piston process the same energy and water amount both during the wave rise and wave fall. Therefore, the water consumption per full cycle will be doubled: Q_cycle=2* Q_wave_rise=276 ml/cycle.
Or per second with 4sec cycle period: Q=Q_cycle/T=68 ml / s=$68*10^{-6}$ m^3 / s.
The power generated by the pump for both working strokes is:
Pow [W] = P [Pa] * Q [m^3 / s] = $5*10^6 * 68*10^{-6}$ = 340 W.
So single float with a pump has 1m^2 dimension and gives 0.34 kW in the form of source water with a pressure of 5 MPa and with a flow rate of 0.000068 m^3 / s =0.25 m^3 per hour=2,140 m^3 per year.
A typical reverse osmosis cycle will produce half of the pumped amount, which is 1,070 m^3 of desalinated water, and about 1,070 m^3 of concentrate per single float with the pump. By recuperating energy packed in the concentrate – amount of the desalinated water could be increased for about 60%, which gives at least 1,700 m^3 per year from a single float with the pump.

In the most advanced reverse osmosis desalination plants (for example, on ship desalination plants), a recovery system could return up to 60% of the concentrate energy [3].

Calculation for the wave height is Hw = 1 m.

Waves with 1m height usually have t=4s period. After performing similar calculations - we'll get: Floats with a pump piston give 0.45 kW from 1 m^2 of sea in the form of source water with a pressure of 5 МПа and with a flow rate of 0.000094 m^3 / s = 94 ml / s, which is 2,900 m^3 per year from a single float with 1m dimension. Half of it (1,450 m^3) will be desalinated water if there is no energy recuperation. With recuperation it will be 850 m^3 more - 2,300 m^3 of desalinated water per year from the single with 1m dimension. At least 4,600 m^3 of source seawater, must be supplied by a booster pump and must undergo preliminary training.

Pontons' shape and sea layout

The layout and shape of the pontoons greatly depends on the applications and conditions. Below are the various possible shapes and layouts. Although, formally, Figs. 6 and 7 relate to the first option with floats, and Figs. 8, 9, and 10 relate to the FOWC - all the proposed shapes and arrangements are interchangeable.

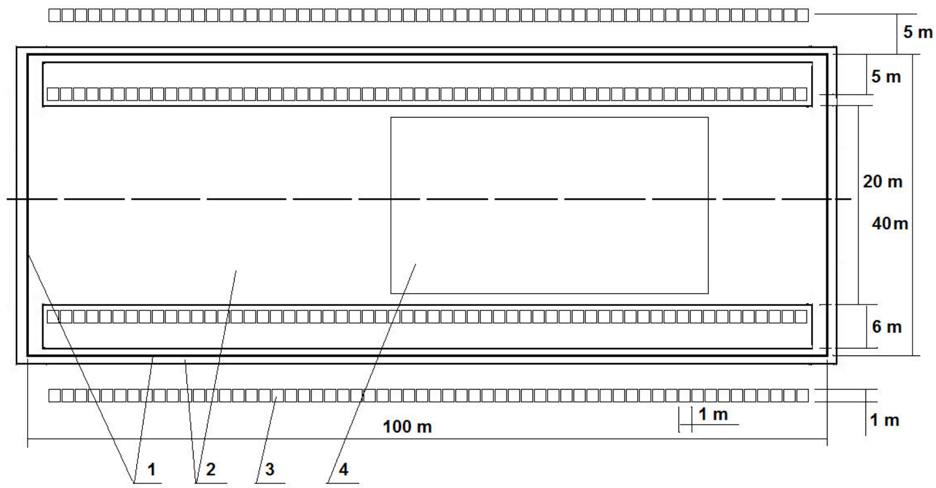


Fig. 6. Pontoon in plan.

Designations in Figure 6: 1 - power floating pontoon trusses, 2 - pontoon deck, 3 - floats, 4 - desalination plant premises, consumables warehouses and staff cabin.

Pontoons are installed at 500 ... 1,000 m off the coast. Layout of the multiple pontoons in the sea is shown in Fig. 7. To protect the coast and pontoons from storm waves and winds, additional equipment is required, which is the topic for another article.

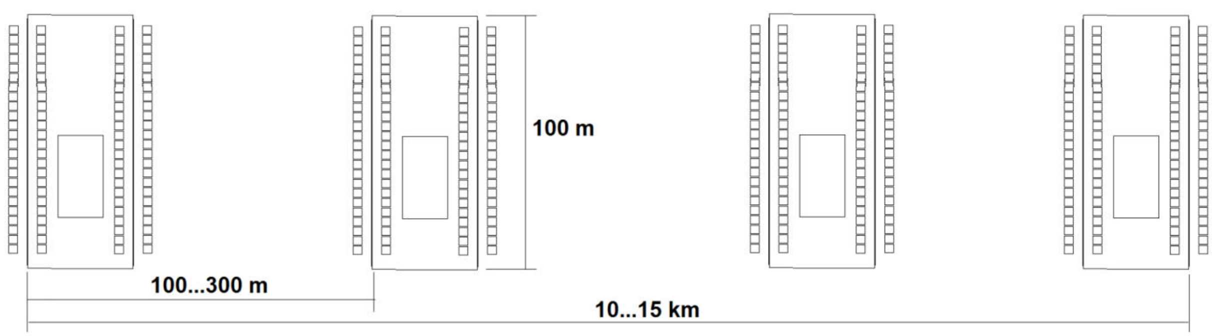


Fig. 7. The Layout of the multiple pontoons in the sea

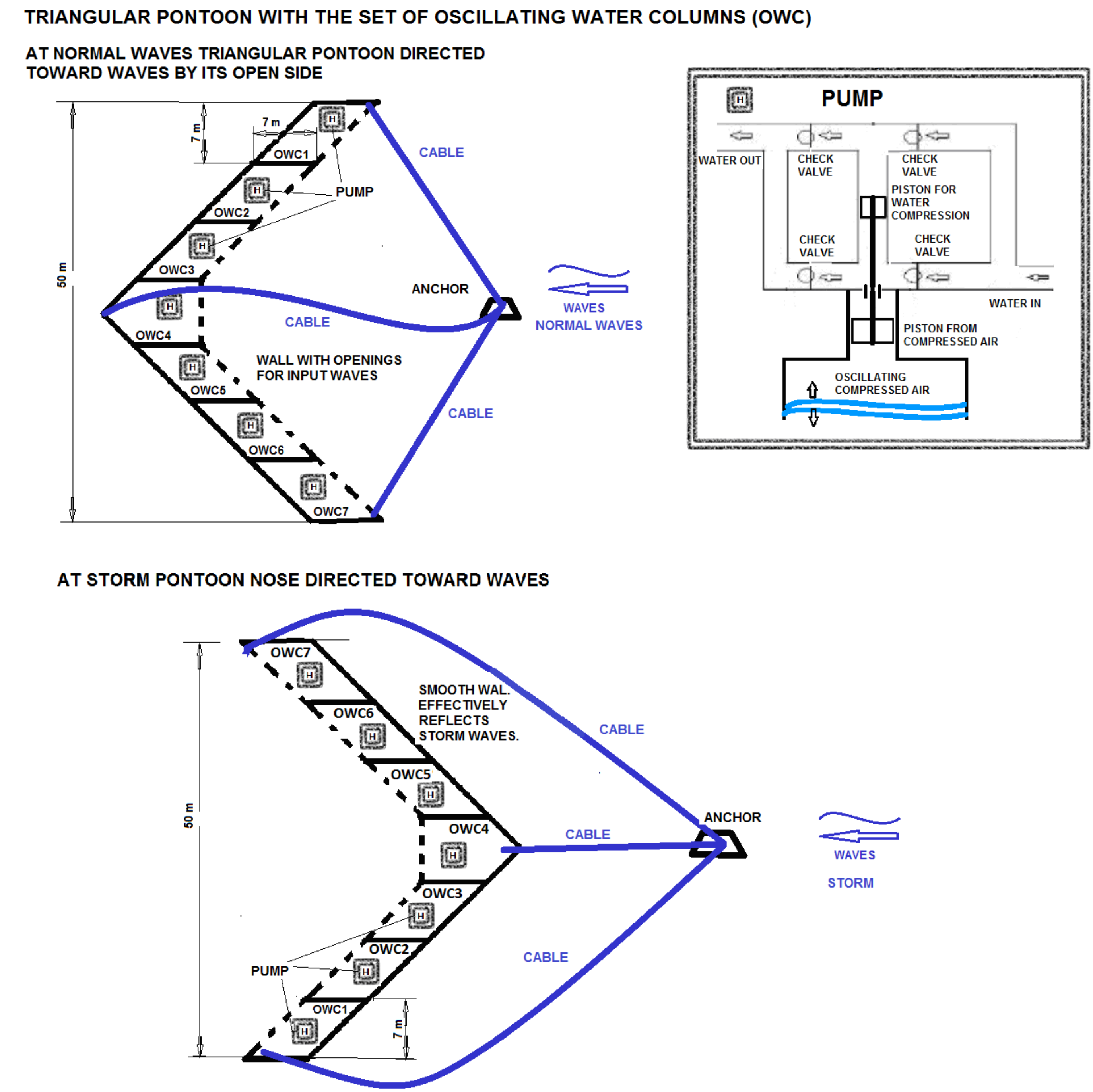


Fig. 8 Triangular ponton with oscillating wave columns and pump. Top figure - at normal wave condition. Lower figure - at storm.

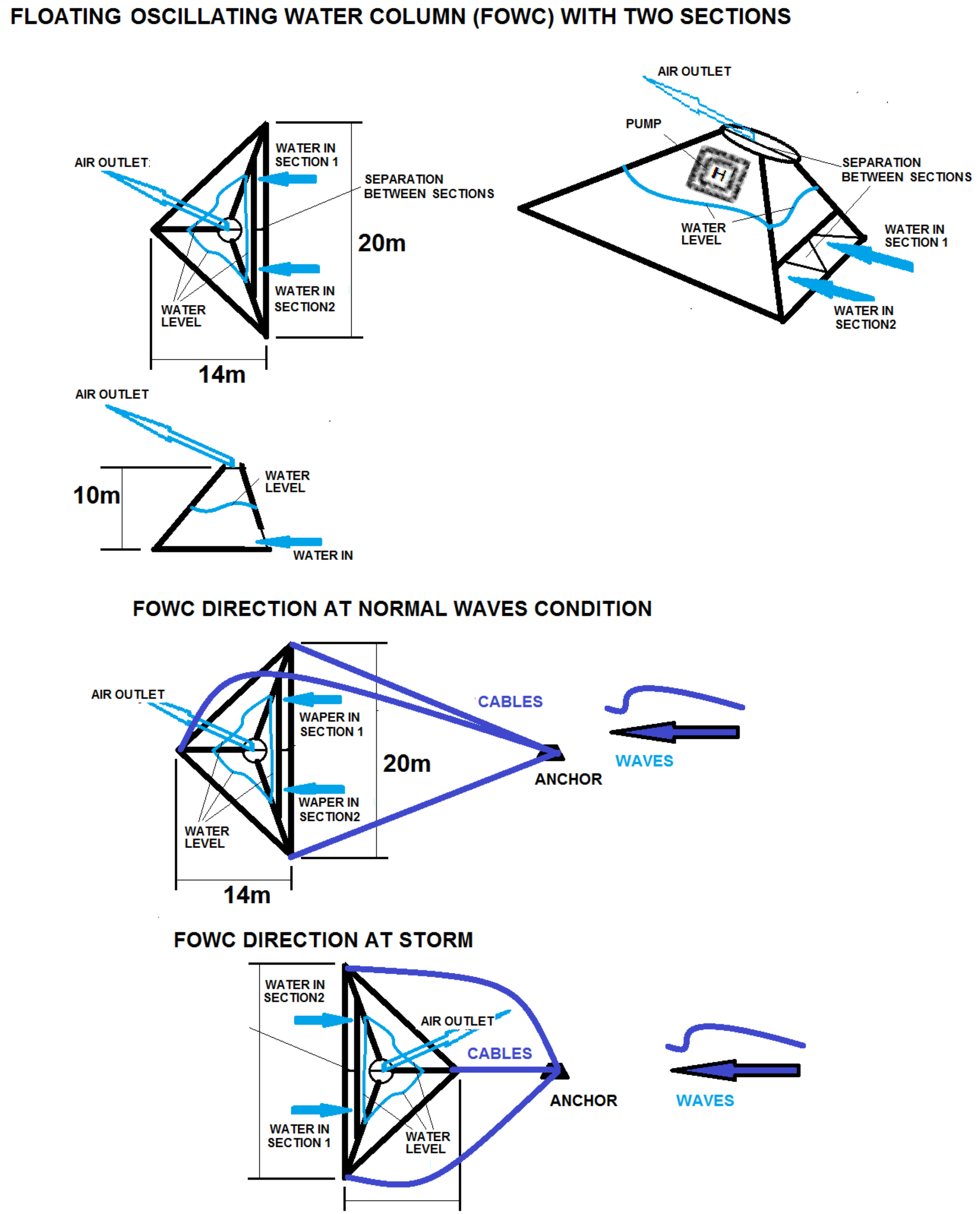


Fig. 9 Triangular ponton with oscillating wave columns with two sections (with higher storm sustanability)
Top figure - design drawing. Medium figure - at normal wave condition. Lower figure - at storm.

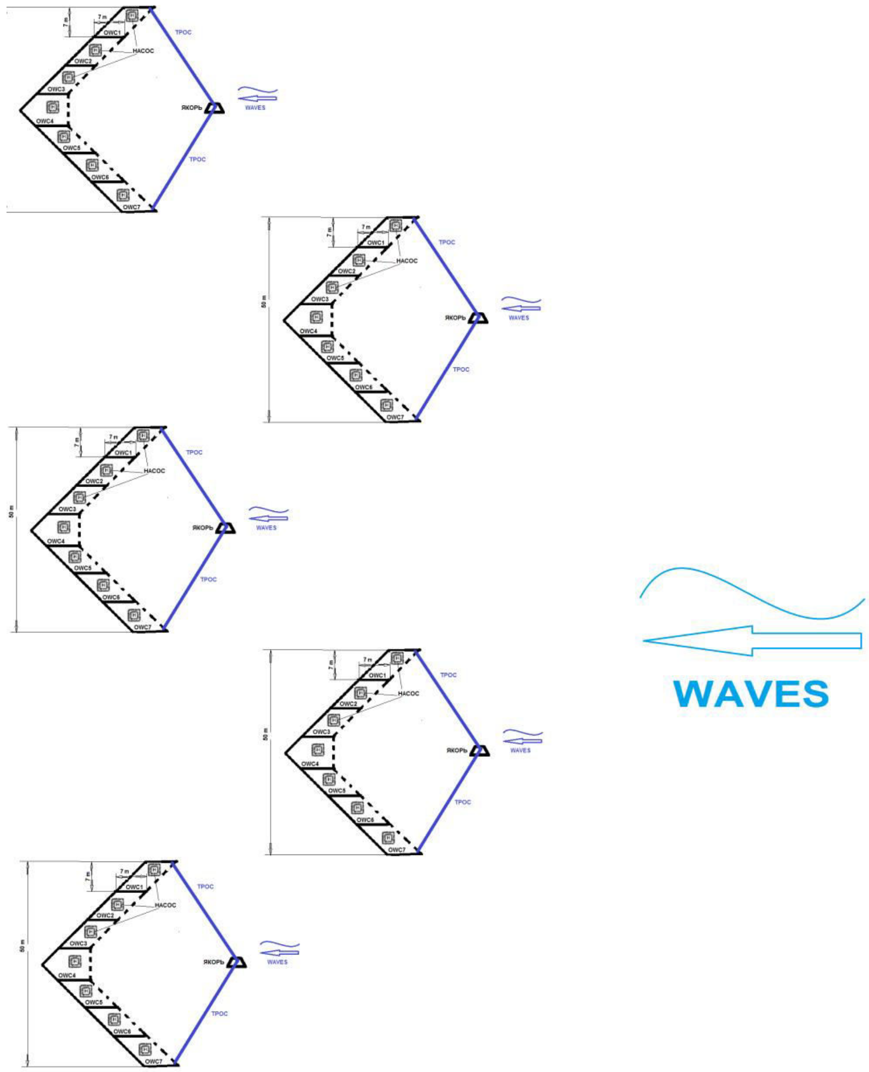


Fig. 10 Sea layout of the triangular pontoons group with oscillating water columns under normal wave condition.

The overall performance of the pontoons

With an average sea wave and a wave height of H = 0.8 m, we have a capacity of at least 1,700 m^3 per year of desalinated water from each float. On one pontoon, we have 400 floats and a productivity of 1,700 * 400 = 680,000 m^3 = 0.68 million m^3 per year and 1,860 m^3 per day (= 680,000 / 365). For example, 100 pontoons with 400 floats each at a wave height of 0.8 m give desalinated water 68 million m^3 per year.

At a wave height of H = 1 m, respectively, we have 100 pontoons with 400 floats each, which give desalinated water 2,300 * 40,000 = 92,000,000 m^3 = 92 million m^3 per year. On one pontoon, the productivity is 2,500 m^3 per day (= 920,000/365).

Peter Taboada is developing custom-made reverse osmosis desalination plants for a new class of cruise liners that MSC Cruises is building at STX Europe. Desalination plant has productivity 1,650 m^3 per day.[3] For our case, it is advisable to have one similar installation on each pontoon. Therefore, it is possible to order a desalination plant with a capacity of, for example, 1,500 ... 2,500 m^3 per day.

To accommodate the proposed desalination plants at sea, an area of 10 ... 15 km per 0.2 km is required. Desalination plants are completely autonomous and have their own sufficiently powerful source of "renewable" electricity. Their performance is determined by the height of the waves and the capabilities of the used equipment. To protect the coast and pontoons from storm waves and winds, separate equipment is needed, which is the subject for another article.

Each pontoon is independent and can be installed anywhere in the sea, near any coast and provide drinking water of the highest quality: Water for supplying cruise ship passengers meets the highest international standards. Pontoons are floating structures, so - they cannot have any negative impact on marine living creatures and other environmental processes and issues.

Economic indicators

Estimated cost of the necessary equipment:
For 1 pontoon, estimated prices for equipment and materials:
- A modular desalination plant costs $ 1,000,000.
- Piston pumps 400 units cost $ 40,000.
- Steel pipes of different diameters of 1.6 km cost $ 120,000.
- The volume and weight of polyethylene foam - applicable polyethylene having a mass of 35 kg / m^3 and a volume of 80 m^3, 1 pontoon requires 2,800 kg, which cost $ 3,000.

Total for 1 pontoon, the cost of equipment is about $ 1,200,000, for 100 pontoons is $ 120,000,000. The cost of other equipment and labor costs for the construction of a floating desalination plant were not considered here due to the lack of reliable information from the authors.
The costs of construction and equipment of desalination plants in world practice are relative to annual productivity, for example,
- in Oman 2.4 $ / m^3 *year [5],
- in Iran 2.5 $ / m^3 * year [6],
- in Crimea 6 $ / m^3 * year [7].

In our case (based on 0.8 ... 1 m an average sea waves), the costs for the construction and equipment of desalination plants on pontoons are no more than 1.6 $ / m^3 * year (= 1,200,000 / 2100 * 365), i.e. approximately correspond to world practice. Electricity consumption at desalination plants is 3 ... 8 kWh per cubic meter of desalinated water, i.e. 0.3 ... 0.8 $ / m^3. It is the cost of electricity that mainly determines the costs of ongoing maintenance of plants. Floating desalination plants receive energy for operation only from sea waves, therefore, there are no electricity expenses. For desalination plants on pontoons, coastal territories and the construction of large capital facilities are not required. 100 pontoons will produce 80 million m^3 per year of water (calculated on average sea waves), which costs 500 ... 700 million shekels, i.e. about $ 160 million.

Description of the desalination plant.
Option 2 FOWC (floating oscillating wave column)

The wave compresses the air that drives the turbine. The dynamics of water in the FOWC is described in detail in [8] and recent tests of the FOWC in [9].

There are no moving parts in the water, which significantly increases storm sustainability.
In our case, the turbine is not needed – because we pumpng and compressing the water directly, which makes storm sustainability even higher.
Efficiency of about 30% [9] is very encouraging.

Thus, FOWC (floating oscillating wave column):
- protects the coast;
- itself has a high storm sustainability;

FOWC can be adapted to the storm by changing the length of the cables see figs 8 and 9.

- during normal waves, the open part is deployed in the direction of the incoming waves - due to the anchoring (Fig. 8, upper figure);
- during a storm, it is turned with its nose in the direction of the incoming waves, which increases the reflection of waves and storm sustainability, but does not stop the energy conversion (Fig. 8, lower figure);
- gives compressed water for reverse osmosis plants.

Adaptation to the storm

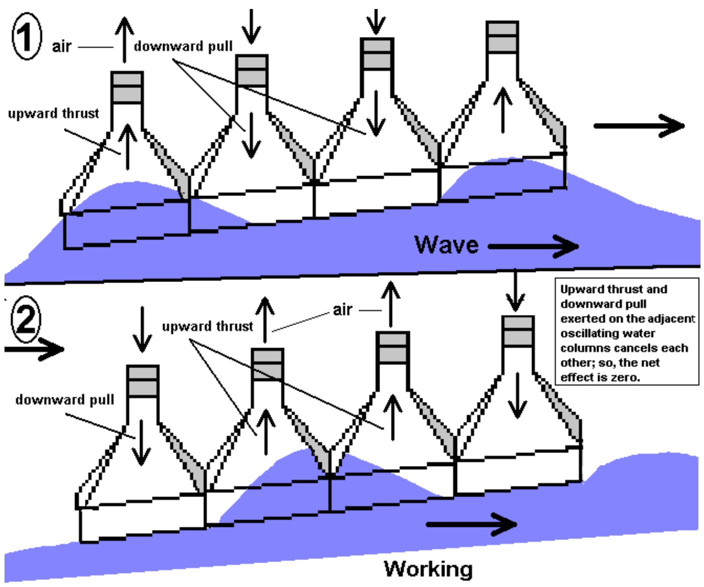
Adaptation of FOWC to the storm can significantly increase FOWC stability and is carried out by changing the length of the cables. This does not mean that such an adaptation guarantees full maximum storm protection, but significantly simplifies and reduces the cost of additional protective measures.

Pump evaluation.

The pump diagram is shown in Fig. 8 above. Its design should be substantially refined and detailed. However, rough estimates can be made. The estimates below are based mainly on the energy balance. Their connection with the real design is only due to the estimated efficiency (about 25%).

We will based our estimation on the fact that:
- The average wave's power is 4 kW / m, which corresponds to a wave height of 1.4 m with a period of 4 seconds.
- Total Efficiency from the wave energy to the entrance to Reverse Osmosis - 25%.
- Pressure for Reverse Osmosis 4 MPa.

Based on this data:
The total energy per one meter of the wave front for one period (4sec) is 4KW / m * 4sec.
Taking into account the efficiency (25%), the available energy per one meter of a wave front for one period is 4 kW / m * sec.
This energy is enough to squeeze 1 liter of water with a pressure of 4 MPa.
7 m of wave front will be able to squeeze out 7 liters in one period.



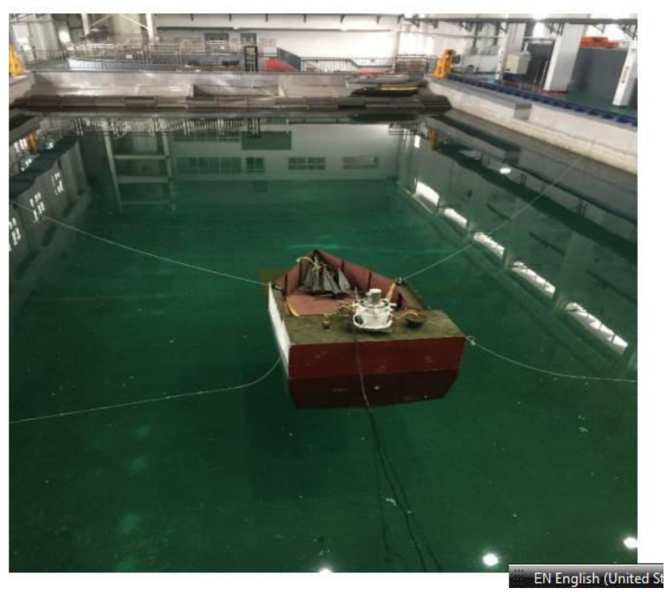


Fig. 11 Illustration of a floating oscillating wave column
Fig. 12 Photo of testing of a floating oscillating wave column [9]

Description of figures for option 2. FOWC (floating oscillating water column)

In Fig. 8 above is a sketch of the proposed triangular pontoon with FOWC and pump.

FOWC can be adapted to the storm by changing the length of the cables.
The direction of the FOWC in Fig. 8 above corresponds to normal wave's condition.
The direction of the FOWC in Fig. 8 below corresponds to storm waves.

FOWC can be just of two sections for better storm sustainability.
The direction of the FOWC in Fig. 9 from below corresponds to storm waves.
In Fig. Figure 10 shows the proposed arrangement of a series of triangular pontoons with FOWC during normal wave's condition.
In Fig. Figures 11 and 12 show illustrations of the FOWC functioning, and a photo of the FOWC under tests [9].

Conclusion

To send this proposal to the City Hall of Netanya and Ashdod and to ask them to find funds to create a start-up with the involvement of their specialists. The goal of the start-up is to protect the coast and obtain high-quality drinking water. As a first step - to ask to build an experimental pontoon.

The considered desalination plant on an autonomous pontoon, which: desalinates water by using sea waves energy only and also reduces the destruction of the sea coast, has enormous international potential. It can solve the problems of drinking water supply to the waterless islands or sea coasts without sufficient sources of electricity.

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