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Large Scale Dew Collection as a Source of Fresh Water Supply

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ABSTRACT

A scheme for large-scale dew collection as a source of fresh water supply is outlined in the present paper. The scheme envisages bringing cold seawater (5^0C) from about 500 meters depth and about 5 km from the shore, in four, 1.22 m diameter plastic pipes. It then passes through an onshore heat exchanger field with an area of 1.29 X 10^5 m^2 (1.39 X 10^6 ft^2) where it condenses 643 m^3 of dew over the 24 hour period. The pumping of sea water from the sea and through the field is accomplished by three 200 kW wind machines. Technical and economical feasibility of the scheme is analyzed and the possibility of marine culture as a source of food is explored. The present scheme is economically not feasible as compared to a RO (reverse osmosis) facility of equivalent capacity.

INTRODUCTION

With increasing industrialization and population, the world's water supplies are being taxed to their capacity. There is already an acute shortage of potable water in developing countries. This shortage has necessitated the use of desalination as a means of providing fresh water for drinking purposes. All of the existing desalination plants in the world use scarce and costly fossil to fire them. Consequently, the majority of these plants are located in Mid East countries [1]. However, the majority of the developing countries cannot get the costly fuel to run the desalination plants, thus pointing out the need of using alternative desalination technology.

One of the simplest desalination technologies that have received hardly any serious attention is the large-scale dew collection. Yet this is one of the major sources of water for plants and some animals in the coastal and inland deserts [2]. In the desert environment the dew collection takes place because of night sky radiation cooling. However, for production of large quantities of water the night sky radiation is not sufficient [3, 4]. An alternative method, which is proposed in the present paper, is to pass the deep sea cold water through suitable heat exchangers for dew condensation. Obvious advantages of the scheme over the existing desalination processes are a) no energy is expended in evaporating the sea water – the air-sea

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interaction takes care of that, and b) because of assurance of constant temperature source of cold water, the dew collection can take place continuously day and night for the whole year.

This paper discusses the technical feasibility of such a scheme and the thrust is given to presenting an overall objective rather than detailed design calculations.

SCHEME

The scheme envisages bringing cold sea water at 4.5^0C (40^0F) from about 500 m (1600 ft) depth in four, 1.22 m (4 ft) diameter plastic pipes to the shore. It then passes through a heat exchanger field (area of 1.29 X 10^5 m^2), where it condenses about 643 m^3 (170,000 gallons) of dew over the period of 24 hours. The pumping of sea water from the sea and through the heat exchanger is accomplished by three, 200 kW wind machines. After passing through the heat exchanger, the sea water goes through a series of ponds where algae and fish are grown. It then returns to the ocean.

Figure 1 shows the schematic of the scheme and Figure 2 is an artist sketch of the scheme. Below are detailed the different components of the system.

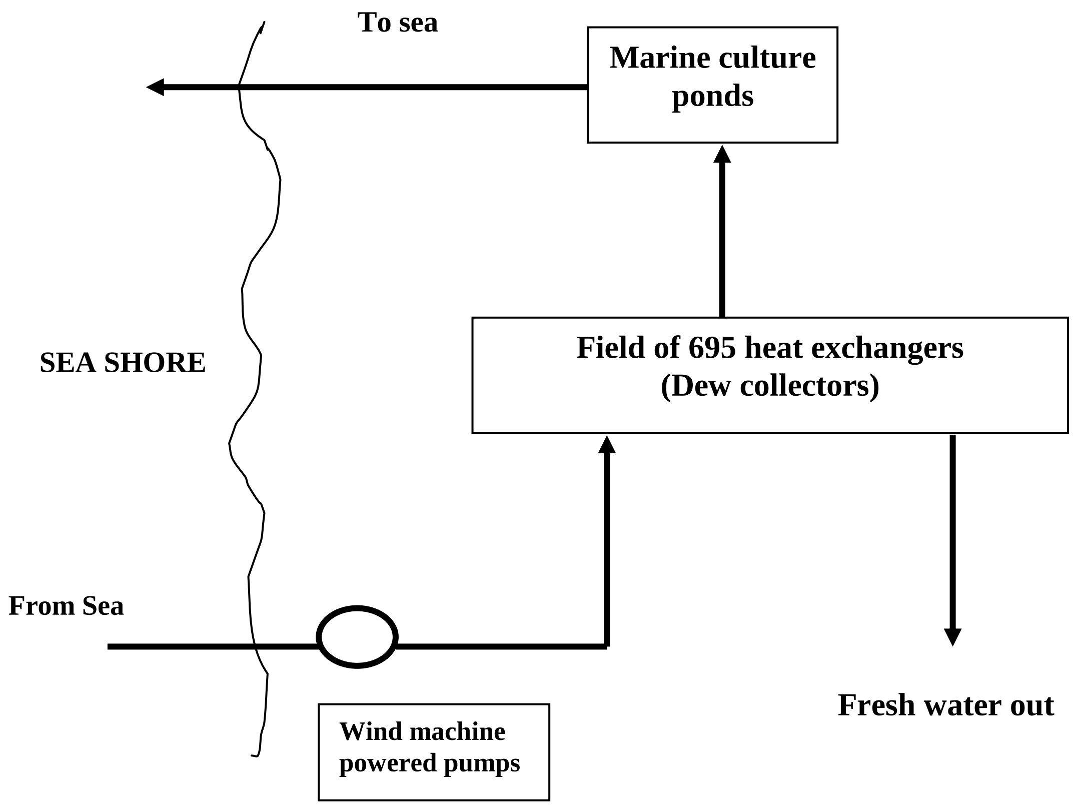

Fig. 1. Schematic of the scheme

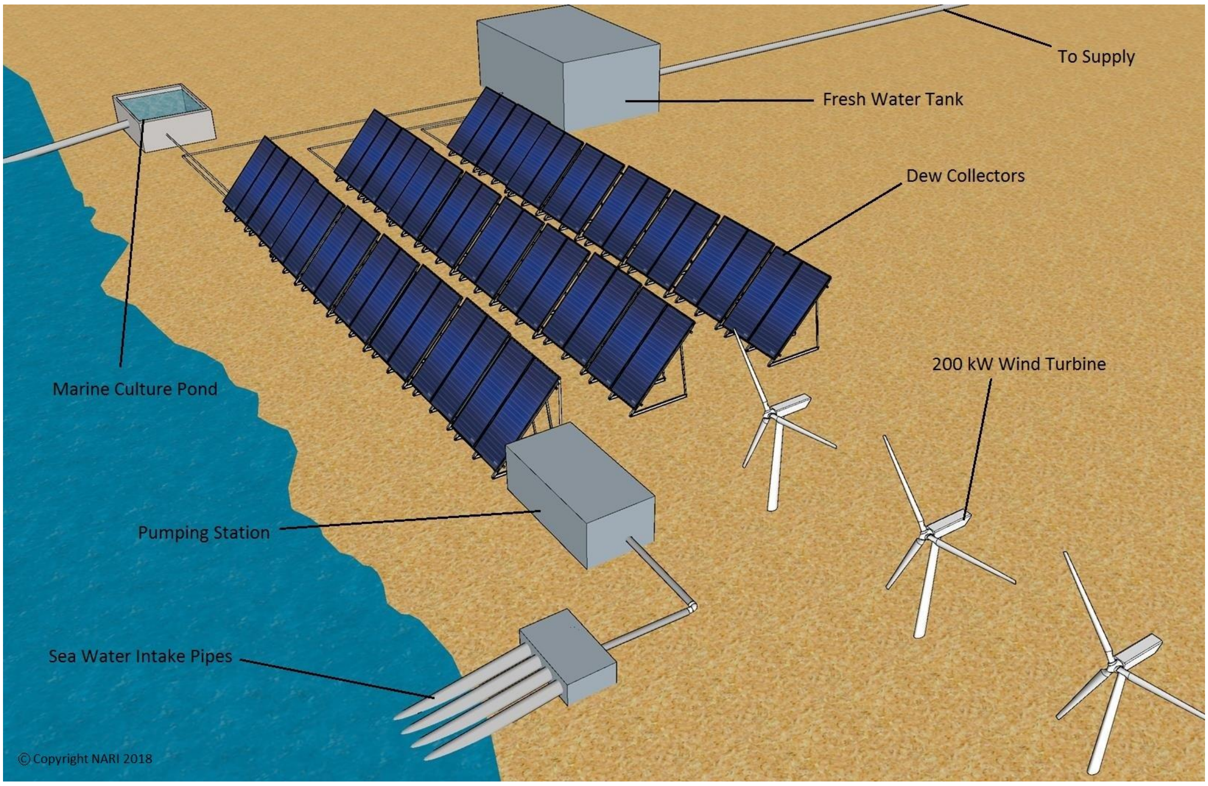

Fig. 2. Artist sketch of the scheme

Heat Exchanger

The condensation of dew takes place when the cold seawater passes through the heat exchanger. Thus the choice of heat exchanger is dictated by the following considerations; a) it should not be corroded by sea water, b) it should effectively exchange heat with environment and c) it should be inexpensive. Based on these points the heat exchanger chosen for the present scheme is an EPDM extruded collector [5]. These collector mats are used for medium temperature hot water heating. In this scheme the EPDM mat (without the glazing and the back insulation) sits on the shore inclined at an angle (about 60 to 70^0) such that the dew condensation takes place on both sides of the mat.

The heat exchanger area for collecting the dew is calculated from the knowledge of condensation heat transfer coefficient. This coefficient has been obtained experimentally [4]. It should be noted that dew condensation will take place anytime when the heat exchanger plate temperature is less than the dew point of the ambient air. Thus even during daytime considerable condensation occurs. The heat exchanger area A_h is therefore given as:

<u>During night</u> :

$$2h_{c+r}\ A_h\,(T_a - T_h) + 2h_{cond}\ A_h\,(T_a - T_h) = m_w\,C_p\,(T_{out} - T_{in}) \qquad (1)$$

$$2h_{cond}\ A_h\,(T_a - T_h)t_n = m_{dew}\,h_{fg} \qquad (2)$$

<u>During day :</u>

$$\alpha\ qs\ A_h + 2h_{cond}\ A_h\ (T_a - T_h) + 2h_{c+r}\ A_h\ (T_a - T_h) = m_w\ C_p\ (T_{out} - T_{in}) \quad (3)$$

$$T_h = \frac{T_{out} + T_{in}}{2\eta} \quad (4)$$

and

$$2h_{cond}\ A_h\ (T_a - T_h)\ t_d = m_{dew}\ h_{fg} \quad (5)$$

The values of variables used in the above equations are shown in Table 1. For the night calculations it is assumed that the temperature of the sea water entering the heat exchanger module will be 10^0C (50^0F) and that at the exit will be 15.5^0C (60^0F). Therefore the average temperature of the heat exchanger plate will be 12.7^0C (55^0F). Since this plant will be on shore hence an average ambient temperature and relative humidity at night is assumed to be 23.8^0C (75^0F) and 100% respectively. The duration of dew condensation at night is assumed to be 10 hours.

Table 1

Property values used in equations (1) to (5)

h_{c+r} = 11.35 W/m^2 ^{0}C (2.0 BTU/ft^2 hr ^{0}F) [13]

h_{cond} = 8.5 W/m^2 ^{0}C (1.5 BTU/ft^2 hr ^{0}F) [4]

t_n ; time for dew condensation at night = 10 hours

Amount of dew condensed at night = 378 m^3 (100,000 gallons)

t_d ; time for dew condensation during day = 14 hours

Amount of dew condensed during day = 265 m^3 (70,000 gallons)

Average ambient temperature at night = 23.9^0C (75^0 F)

Average ambient temperature during day = 26.6^0C (80^0 F)

Average solar radiation = 12.7 MJ/m^2 (1120 BTU/ft^2 – day)

Relative humidity ~ 100%

η , heat exchanger efficiency = 0.9

All the above property values are taken as average conditions for locations between 30^0 N and 30^0 S latitudes.

For the daytime calculations average solar radiation and ambient temperature have been assumed. Thus over a period of 14 hours the solar radiation is assumed to have a value of about 252 W/m^2 (80 BTU/ft^2 hr) and ambient temperature of 26.6^0C (80^0F). These are reasonable assumptions for sea shore conditions [6]. From equation (1) the mass flow rate of sea water flowing through the heat exchangers is calculated and is 8.31 X 10^6 kg/hr (18.3 X 10^6 lbs/hr). This value is held constant during the daytime also.

Each collector module is assumed to be 18.6 m^2 (50 ft X 4 ft) in area. This choice of area has been dictated by the ease of maintenance and installation. Thus the total number of collectors is 6950. It should be pointed out that the value of h_{c+r} in equations (1) and (3) is that for still air. Near the sea shore the conditions are far different from still air. However, the collectors are arranged such that they are normal to the direction of the wind (coming from the sea) and thus act as wind breakers, thereby justifying the assumption of h_{c+r} .

Sea Water Intake Pipes

The choice of sea water intake pipe is governed by the following considerations; a) it should be noncorrosive with sea water b) it should withstand the tides and the wave motions, c) it should provide excellent insulation for the cold water during its passage to the shore and d) it should be easily assembled. Based on these criteria the pipe chosen for the present scheme is a 1.22 m (4 ft) diameter plastic pipe with wall thickness of 3.7 cm (1.45 inches) [7]. Four such pipes will bring the required water to the shore.

The cold sea water of 4.5^{0}C (40^{0}F) is mostly located at a depth of about 500 m (1600 ft) [8]. Moreover, the present scheme has been designed for locations where about 500 m deep waters are available at about 5 km or less distance from shores [9]. Heat transfer calculations for a 5 km plastic pipe show that the temperature rise of cold water of 4.5^{0}C (40^{0}F) will be less than 0.27^{0}C (0.5^{0}F) in reaching the shore. Thus the plastic pipe provides adequate insulation. These calculations have been performed assuming a sea water temperature profile [8] and the flow rate of water of 2.1 X 10^6 kg/hr (4.6 X 10^6 lbs/hr).

Pumping Requirements

Table 2 shows the pressure drop in various sections of the scheme and the pumping requirements. The total pressure drop is about 176 kPa (60 ft of water). Near the sea shore there is a constant wind and thus it is appropriate that the wind machines be used to operate the pumps. Three 200 kW wind machines will adequately perform the pumping of sea water through collectors. Since the wind is constant near the shore no attempt has been made to store the water in the overhead tanks. This storage would have been necessary to overcome the pumping loss during wind-lean periods. It is also interesting to note that any energy input in the present scheme is that from the wind machines which make this scheme consume ≅ 57 kW hr/1000 gallons. This energy requirement compares very favorably with that used in RO units (65 kW hr/1000 gallons), and MSF (315 kW hr/1000 gallons) [10]. This is to be expected since no energy is expended in evaporating the water.

Table 2

Pumping Requirements

	Pressure drop kPa (ft of water)	Flow rate kg/hr (lbs/hr)
Sea water intake pipe (4, plastic)	19.4 (6.5)	2.1×10^6 (4.6×10^6)
Header to modules (3, plastic)	113 (38)	4.2×10^6 (9.2×10^6)
Header of modules (20, plastic)	23.9 (8)	0.82×10^6 (1.8×10^6)
Collectors (6950, EPDM)	11.9 (4)	1.2×10^3 (2.6×10^3)
Return pipe to sea (1, concrete)	5.97 (2)	8.32×10^6 (18.3×10^6)
Total pressure drop	176 (59)	8.32×10^6 (18.3×10^6)
Power requirements of about 450 kW		
Number of wind machines @ 200 kW =3		

Mariculture ponds

The deep sea water is an excellent feed producer for mariculture crops [9]. After passing through the heat exchanger it can easily be run into deep ponds (≅ 6 m deep) to produce algae, which is a rich protein source. These algae then can be a source of food for growing fish and clams [9]. Thus besides providing the much needed water for the locality this scheme will also provide a source of protein and food. Based on the results of the pioneering work done in the St. Croix island by Roels and his group [9], the present scheme will produce about 870 tons/year (wet weight) of shellfish. It should be noted that in the existing desalination plants such a scheme (of mariculture) cannot be implemented because of lack of deep sea water.

Finally for the sake of completeness of the study a preliminary economic analysis of the scheme has been done. Assuming the cost of wind machines at $ 600/kw [11], the cost of heat exchangers at $ 30/m^2 (≅ $ 3/ft^2) [5] and the cost of 1.22 m (4 ft) diameter plastic pipe at $ 262/m ($ 80/ft), the capital cost of the scheme comes out to be $ 11 million. The price of this scheme should be compared with the existing desalination plant of an equivalent capacity. For comparison we have assumed a reverse osmosis (RO) scheme [12]. Even taking the escalating fuel prices (at 15% annual increase) into account it has been found that RO plant will be cheaper than the existing scheme by a factor of 2.5. However, if the fuel prices suddenly double or triple then the present scheme (dew collection) will become economically viable. It should be pointed out that the whole purpose behind presenting the idea of dew collection is to create awareness of the technical merits of this scheme. Nevertheless, it is felt that with better technology and materials of various components the scheme has capability of becoming economically viable. For example the two main components with the highest price tags are the heat exchanger field ($ 4.2 million) and sea water intake pipes ($ 5.3 million) respectively. If the field can be made of tubular heat exchangers rather than the flat plate (as the present scheme) considerable savings in the cost can be achieved. In the absence of any experimental data on dew collection on tubular heat exchangers we have chosen the flat plate (for which the data exists [4]). Similarly cheaper pipes for sea water intake will reduce the cost of the scheme.

It can also be conjectured that in the future the OTEC (Ocean Thermal Energy Conversion) schemes may very well become floating desalination plants with the cold water from the bottom used for dew condensation. The production of fresh water may make OTEC economically viable since the generated commodity (in this case fresh water) can be easily transported to shore in huge plastic tankers. Right now no viable scheme of getting the generated power from OTEC plants to the shore exists [9].

CONCLUSIONS

The following conclusions can be drawn based on the present study.

1. Large scale dew collection near the seashore for production of fresh water is technically feasible.

2. A heat exchanger field of area 1.29 X 10^5 m^2 (1.39 X 10^6 ft^2) can condense 643 m^3 (170,000 gallons) of dew over a period of 24 hours.

3. The cold water for dew condensation is obtained from a depth of about 600 m. The pumping of 8.32 X 10^6 kg/hr (18.3 X 10^6 lbs/hr) of this cold water is achieved by 3, 200 kW wind machines.

4. This present scheme is economically not feasible as compared to a RO facility of equivalent capacity.

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NOMENCLATURE

A_h	heat exchanger area, m^2
C_p	specific heat, kJ/kg ^0C
h_{fg}	enthalpy of vaporization, kJ/kg
h_{c+r}	combined convection and radiation heat transfer coefficient, $W/m^2\,^0C$
h_{cond}	condensation heat transfer coefficient, $W/m^2\,^0C$
m_{dew}	amount of dew condensed, kg
m_w	rate of sea water flow, kg/hr
q_s	incident solar radiation, W/m^2
t_d	duration of dew condensation during day, hrs.
t_n	duration of dew condensation during night, hrs.
T_a	ambient temperature, ^0C
T_h	temperature of heat exchanger place, ^0C
T_{in} , T_{out}	temperature of sea water entering and leaving the heat exchanger respectively, ^0C

Greek letters

α	solar absorptivity of the EPDM mat
η	heat exchanger efficiency

A short history of water related R&D at NARI is here.