A short history of water related research at NARI.

(Chapter from the book "Romance of Innovation")

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Quite a lot of work described in this document was done by me in 1970s when I was a graduate student and later on a faculty member of Mechanical Engineering Department in University of Florida (UF), Gainesville, U.S.A. I feel that quite a number of problems explored and tackled at that time have still remained unsolved and hence my desire to put them down in this article.

Recently I have summarized the work reported in this essay in an Institute Lecture and Inaugural talk delivered at IIT Bombay.

Potable water

Sea water desalination

In late 1974 I went to UF to do my Ph.D. in solar energy under the solar pioneer Dr. Erich Farber. Since I was a Government of India scholar with full fellowship hence, I was not dependant on UF professors for funds and topics of research. Thus I had the liberty to choose any subject of my choice for Ph.D. work. That naturally put a lot of burden on me.

So when I started my Ph.D. coursework in January 1975 the main focus was to find out various areas of research. From my reading of solar literature it appeared that the best topic would be desalination of sea water using solar energy.

In early 1970s world did not have shortage of water but reading the predictions by some of the leading water experts convinced me that in future more than the energy crisis, world will suffer from water crisis. Hence, I felt that desalination of sea water should be the focus of research.

In my research I also realized that nature has all the answers and hence the best course of action was to follow nature in our design. This was much before the time when biomimicry, as it is called today, became a buzz word.

Nature produces rain from salty seas and hence it is the world's biggest desalination plant. Thus the idea was to duplicate in my design the whole process involved in rain making. Naturally this was a tall order and proved to be very difficult to implement.

Since evaporation of water takes place from the surface of sea, I became interested in the surface phenomenon. Quite a number of courses on surface science which I took at UF showed me that surface acting agents called surfactants (basically soaps) may play a role in enhancing sea water evaporation. I found out that plankton and other biological material found in sea water may be acting as surfactants. So I did many experiments in chemical engineering lab of Dr. Dinesh Shah on the role of surfactants in evaporation of sea water.

Theory showed that since surfactants help in reducing the surface tension of water, they might help in increasing water evaporation. In practice the tight packing of surfactant film on the water surface inhibits its evaporation. In fact surfactants are used quite often on lakes and ponds to reduce water evaporation.

Evaporation of water under high voltage (1975)

So the idea came to me that if the surfactant molecules at the surface could be perturbed then the water molecules could wiggle through the surfactant layer and evaporate, similar to what may be happening at the sea-air interface.

In nature this perturbation of surface (production of waves) happens because of wind but in an enclosed environment I thought a better way could be to apply high A.C. voltage field to flip flop the surface.

In order to understand the effect of high voltage on water surface I decided to take courses in electromagnetic field theory. The Electrical Engineering professor under whom I took these courses allowed me to use his lab for my high voltage experiments. Hence, I did quite a number of experiments on the use of high voltage (up to 20 kV both A.C. and D.C.) to perturb the surfactant layer at the surface. Some enhancement of evaporation was seen, but results proved to be inconclusive. Besides, in the enclosed environment of distillation apparatus, the condensing film of water sometimes created short circuits in the apparatus. In one experiment I could produce artificial lightening discharges in the still.

The use of high voltage for desalination was also studied because I wanted to duplicate the affect of lightning on water condensation inside my still. Lightning in clouds result because the evaporating water droplets get charged. How they get their charge is still a mystery. Lightning nevertheless helps in rain formation by accelerating the seeding of clouds. Hence, I wanted to create artificial lightning in the still by using high voltage to charge the evaporating water.

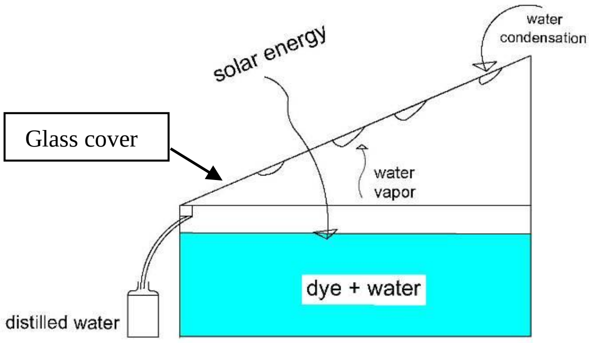
Discussion with Dr. Martin Uman the pioneer of lightning research at UF showed that it was a tall order, and I was biting more than I could chew! So I abandoned this line of research.

Nevertheless I became interested in the phenomenon of how evaporating water gets its charge and is transferred to the clouds. This line of research led me to the work of Irving Langmuir at General Electric (GE) who had studied the charge production from an evaporating cup of coffee and had done pioneering work in cloud seeding.

Langmuir was a great scientist and the first industrial chemist to get the Nobel Prize. I became so fascinated with his life story that later on I wrote a biographical essay on him which was published in Resonance – India's leading journal. One of the outcome of this fascination with Langmuir was my discussion and correspondence with his colleague at GE, Vincent Schaefer, who was the father of cloud seeding. From him I learnt the fascinating account of his experiments in cloud seeding.

Thus the next best thing was to duplicate the absorption of solar energy in the sea for its evaporation. Studies showed that within one-to-two-meter depth from the surface of ocean the solar energy is completely absorbed, and this heated surface water, with the help of wind, evaporated to form clouds. Recently studies have also shown that plankton at the surface of ocean absorbs solar energy and converts it into heat thereby increasing surface temperature and consequently evaporation of water.

Thus I developed the strategy of using different colored dyes in a solar still to simulate this effect. The dyes absorbed the solar energy at the surface and hence increased the evaporation of water. The evaporated water was condensed under the glass cover and collected. This is the basis of simple solar still (pictured).



Solar still

This strategy formed the basis of my Ph.D. thesis entitled **"The effect of dyes on solar distillation."** and was published as a paper in Solar Energy Journal in 1979. It is quoted extensively in solar distillation literature. I also wrote a paper with one of my professors Dr. C. K. Hsieh on how condensing water droplets under the glass surface reflects and passes solar energy to the still. This paper has also been widely quoted in the solar energy literature.

Though this gave me the Ph.D., the desire to learn how nature produces pure water for life led me to undertake studies on the mechanism of how mangroves and sea grasses grow in salt water and how some of the plants (called epiphytes) take water from air.

Studies of mangrove showed that their root systems develop a suction pressure of 30-60 atmospheres which is far greater than the thermodynamic limit of 25 atmospheres needed to desalinate sea water. The osmotic pump in the mangroves and sea grass is the evapotranspiration of water through their leaves. This transpiration of water from the leaves together with a molecular chain of water in the phloem (inside the bark in the outer layer of tree) is also the mechanism of transporting the water up to 100 meters in tall trees. Nature is very efficient and pumps water through tall trees without a pump with moving parts.

Further studies on how water is transported in trees showed that within very thin capillary tubes of phloem, water forms a molecular chain till the surface of leaves and each evaporating molecule from the leaf's surface pulls this chain up resulting in the flow of water through tall trees. In early 1970s there was no mechanism available to make such a structure. However with advancement of nanostructure science and technology, I feel that very thin and long glass capillaries filled with water can be fabricated and could be the basis of a ***very effective pump and a solar desalination device***. Such a system will run only on solar thermal energy without any moving parts.

Based on the work in solar energy at UF, I also developed a simple method to heat water using tubes buried in the solar-heated sand (pictured below). Thus a concrete tube half-buried in sand could heat the water very effectively since sand acted as a giant solar collector. This method formed the basis of my paper published in 1980 on a large scale scheme for desalinating sea water for potable purposes in Thar Desert in Rajasthan.

UF Lab 1979

The scheme envisaged taking water from sea and passing it through sand buried concrete collectors. The heated water would go through the multistage flash evaporating system to produce fresh water. This is like a regular thermal desalination plant except that instead of using fossil fuels like oil and natural gas to run them this plant used solar energy. Again this paper is referred to by lots of researchers and even 35 years after its publication requests have come from all over the world enquiring about the future of this concept. I feel that even today this concept is as valid or even more than it was in 1980.

After my return from US to India in 1981 I got deeply involved in developing rural household devices and energy devices running on biomass. Still I continued some work related to water.

In late 1981 I had gone to Chilika lake in eastern state of Odisha. This lake is the second largest brackish water lagoon in the world with water inflow from Bay of Bengal. It has the largest migratory bird sanctuary in Indian sub-continent and has large area and mass of sea grasses. I collected samples of this grass and planted them in a specially made saltwater tank at NARI. The idea was to see whether sea grass increases the water evaporation from such tanks. We found that because of the increase in surface area (area of leaves) the total evaporation from the tank containing sea grass was more than that from a tank without the grass. This showed that a solar still with sea grass in it could have higher distilled water productivity than the one without it. Unfortunately other activities at NARI took precedence and I left this work unfinished.

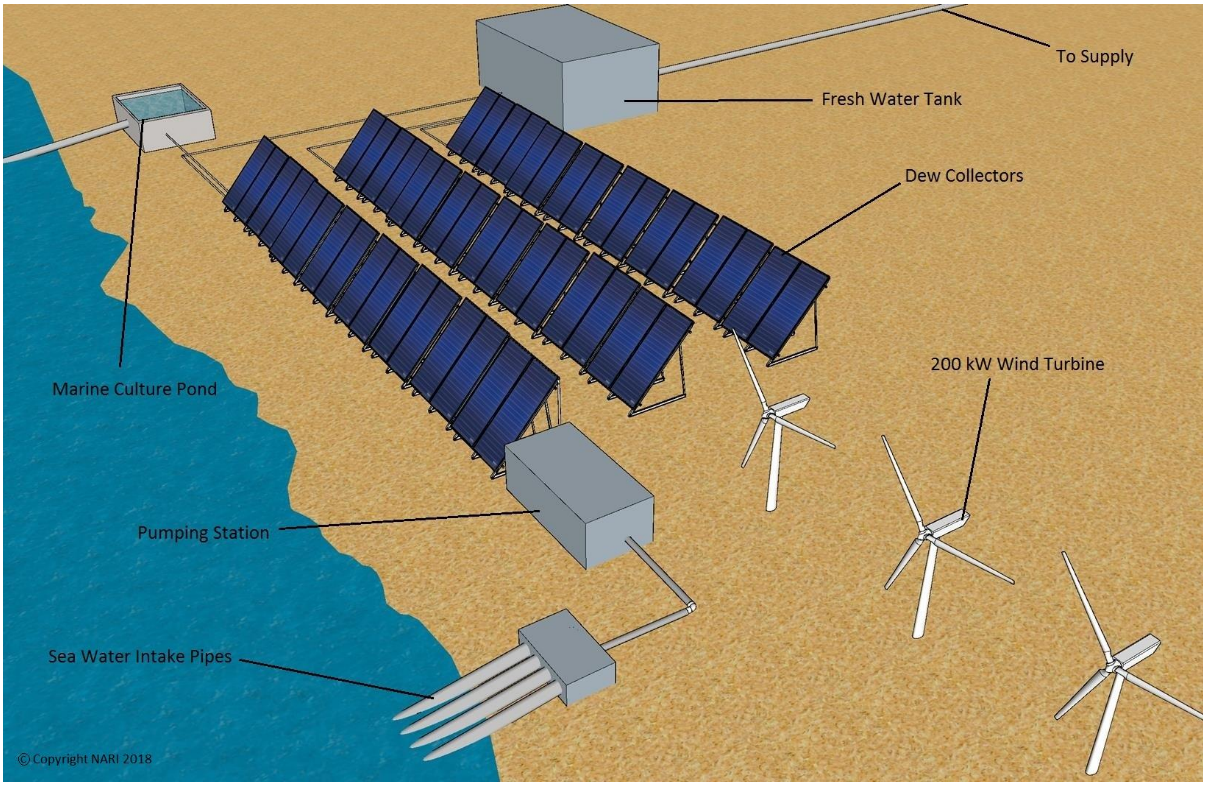
However even today I feel that ***such a unit with enhanced evaporation by sea grass and the use of grass biomass to produce energy will be an excellent system to produce both potable water and electricity near the seashore.***

Dew condensation

In Florida almost all the trees had Spanish moss hanging from their branches. The moss uses the tree branch for support but survives by sucking water from the air. Hence, I became interested in the mechanism of how they suck the moisture from air (basically dew) and then a thought came that for large scale water supply in coastal areas of the world dew condensation maybe a better strategy than desalination since nature has already evaporated the water and hence the energy for evaporation can be saved in such a scheme. A chance news item in early 1979 on how dark beetles in Namibian desert condense dew at night on their outer shell and use that water to survive in harsh desert climate, made me think on how to duplicate natural design for dew condensation system.

Dew condensation setup. UF 1979

Since no reliable long term dew condensation data existed, I decided to generate it. Thus I rigged up a small dew condensation plant consisting of a solar collector sheet through which cold water circulated from a one-ton refrigeration plant. This set-up condensed the dew at night on the aluminum panels and was collected in bottles. ***The plant was daily run for 4-5 months and to my mind was the first long- term dew collector anywhere.*** It gave us very good thermodynamic data on the various parameters affecting dew condensation such as affect of ambient temperature; humidity; wind speed, etc. Based upon this data I developed a scheme for large scale dew condensation as a means of fresh water supply and published it in Desalination Journal.



Schematic of Dew Condensation plant

The scheme envisaged bringing in deep sea water which is very cold (~5-6^{o} C) and passing it through the dew condensation collectors to condense dew. The plant was envisaged to be near the seashore so that wind turbines could be used to pump water from the sea. Returning sea water from the dew collectors would also be used for marine culture and growing fish.

This 1981 paper is still quoted and was ***probably the first paper on this subject of large-scale dew condensation for freshwater production.*** The scheme has been copied and patented by researchers and developers all over the world. Today dew collection and harvesting (also called fog collection) for water production is a hot topic for R&D. Recently there was a news item about how deep sea water could be used for air-conditioning of buildings located near sea shore – something about which we wrote in 1980s!

In 1984 I was invited by Municipal Commissioner of Mumbai to advise him and his team on how to have an alternative water supply for Mumbai. Apparently the then Prime Minister Rajiv Gandhi's office had instructed him about the threat to Mumbai water supply from Pakistani agents and hence an alternative water supply was necessary. Somebody had also told the Commissioner about my work in dew condensation and solar distillation.

So a special meeting was called in his office in Mumbai where I met him and about 10-15 senior staff members to discuss the issue.

I told them that the best way to solve Mumbai water supply problem was to have rainwater harvesting mandatory in each housing society and to collect the condensate from the innumerable air conditioning units operating in Mumbai. This idea was far ahead of its time and rainwater harvesting became fashionable only in late 1990s.

Most of his staff laughed at my suggestion and said that they had gathered there to hear from me and discuss some serious solutions! I then told them about the recent development of offshore ship-based desalination units which were being developed in Sweden. Immediately they all perked up since they saw a strong possibility of going to Sweden and Europe on a fact-finding trip!

Today both rainwater harvesting and dew harvesting through artificial refrigeration is being practiced world over and I feel that Mumbai would have benefited if they had started on these suggestions in the early 1980s.

Another interesting idea that I worked on in Phaltan in early 1980s was use of cloud suction for producing water. Phaltan is in rain shadow area of Sahyadri mountain range and its elevation is around 800 m above sea level. Because of the Western Ghat mountains the clouds from the Arabian sea, during the regular Indian monsoon, go over us and rain further east. We get our scanty rains (~ 500 mm/yr) mainly in September/October during the returning monsoon time.

This made me wonder whether we can somehow suck the clouds and condense them to produce water. This was basically an extension of my dew condensation work. *So I developed a paper study for a scheme of large kites (in the shape of air foils) which would fly high in the sky (about 500 meters or so) and with wind power (wind is plentiful at those heights) the kite would suck the clouds and channel them through the tube which would also double up as "Kite string".* On the ground a suitably designed refrigeration plant running on wind energy would condense these sucked clouds to produce pure water. One of the major design challenges was the stability of kite structure with cloud and wind loading.

Since then many schemes on the use of kites for wind power have been proposed and developed but none for cloud suction and condensation and I still feel that this scheme has merits. The advantage of this scheme over cloud seeding is that one can get water wherever it is needed. In cloud seeding one cannot predict where the rain will fall.

Water sterilization and rainwater harvesting

As we were developing energy devices for rural households, we became acutely aware of the lack of potable water in these households. Hence, we thought of using solar energy to boil water. Thus we set up in 1984 a double-glazed solar collector which boiled the water in stagnation mode in batchwise process. However it did not work during the rainy season (June-September) because the solar radiation was drastically reduced and thus the water could not reach boiling temperatures. Hence an idea arose whether we could make water potable at sub-boiling temperatures – those that are easily reached in solar water heaters.

Recently in 2012 we have developed a system where the dirty water is passed through four layered cotton sari cloth and this filtered water is heated to 60°C for 10-15 minutes. This treatment called Solar water purification (SWP) removes all the coliforms and makes the water potable. This low temperature heating can be easily achieved even on cloudy days in efficient tubular solar collectors. We have set up a small experimental unit and it shows excellent results. Even on the cloudiest days the water temperature is high enough to kill all the coliforms. Thirty liters system supplies the drinking water for the Institute staff.

We also feel that the hot water from the solar sterilizer unit can be used to produce ice via the ***intermittent ammonia-water absorption unit***. This ice can be supplied to each rural household and can be used in an extremely efficient insulated box to provide small refrigerator facilities. The challenge is to develop this ammonia-water system and the insulated box so as to make the whole system economically viable. We feel the solar sterilizer can provide both potable water and refrigeration simultaneously for rural poor.

Recently we have extended this work of solar water sterilization to also ***include rainwater harvesting.*** Thus we have shown that rainwater harvesting from a single housetop dwelling and sterilizing the water with our SWP can meet the complete yearly demand of drinking water requirements for a family of four. We also feel that this system of rainwater harvesting and SWP is also an excellent solution for providing safe drinking water for rural schools.

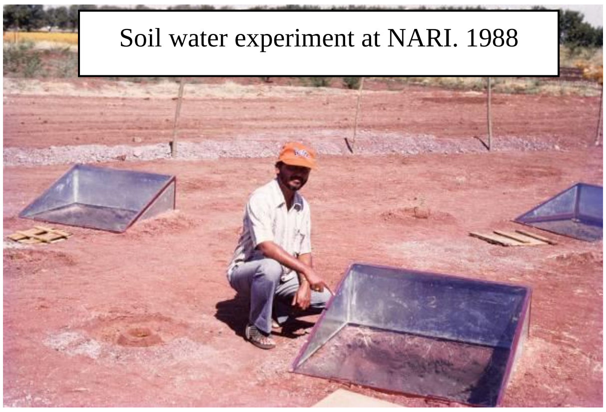
Water for trees

In early 1980s there was a major program of Government of India to increase forest cover in India. Hence funding and seeds were provided to various agencies to plant different types of fast-growing trees. Phaltan area in early 1980s had very little greenery and tree cover and most of the trees planted died in early stages because of lack of water.


NARI 1988

During my UF desalination work I had come across studies on producing water from soil for survival in desert. The technique involved digging a hole of about a foot in diameter and covering this hole with a plastic sheet. This plastic sheet was sealed from the sides and weighed down by a small stone in the middle. A small cup was put in a hole below the weighed down plastic sheet (shown in photo). Moisture in the soil heated by solar energy evaporated and condensed on the underside of the plastic sheet and in one day a cup full of water was available for survival.

I thought of using this technique for producing water in semi-arid regions like Phaltan and then giving this water via drip irrigation to tree seedlings. So instead of plastic covered pit we made the top cover of glass just like that in regular solar water still and put it over the pit. The sides of the still were sealed by the soil.


Soil water experiment at NARI. 1988

We also developed the long-term data and studied the effect of various climatic parameters on soil water evaporation in Phaltan area and found that even in the driest season enough water (about 250-300 ml/day) could be collected from a 0.9 m X 0.9 m X 0.6 pit. This was sufficient for the seedlings to survive. We presented [this work in the International Solar Energy Conference in 1991 in Denver](), Colorado, USA and it was the first paper on such a concept of greening the desert! Since then this pioneering concept has spawned similar efforts all over the world.

These solar stills were reusable and long lasting and once the seedlings were established, they could be put over the new pits. Besides being made of steel they can last for 10-15 years. The empty pits also act as rainwater harvesters and helps in supplying it to the roots of the germinated trees.

In 1991 we gave the design of the solar soil water still to National Dairy Development Board (NDDB) in Anand for producing potable water in Kutch area. Dr. Varghese Kurien, the Chairman of NDDB at that time had invited us to see the condition of salt makers in Kutch area and to suggest how they can produce potable water. The water table in these areas is quite high-almost at the surface and the water is brackish. So we thought our soil water still will be very useful for producing clean water. NDDB made a good number of stills based on our design and we were informed that it supplied adequate potable water for the salt makers. In recent times this idea was nicely covered in mass media.

Another interesting experiment on water conservation we did was to take a barren piece of land (~16 acres) in a nearby village Vinchurni and tried to rejuvenate it by planting fodder trees (Leucaena), cactus (opuntia) and grasses with very little water from a well. The land was slopy and mostly rocky with the topsoil washed away by rain. The experiment was started in early 1990s and now after 30 years the land is lush and green.

Land in 1990s

Leucaena as fodder crop with Cenchrus grass

Solar detoxification of distillery waste

During our work in late 1980s on solar distillation of ethanol we found that for each liter of ethanol distilled about 15 liters of effluent is produced. This effluent which is black in color, very foul-smelling and has high biological and chemical oxygen demand (BOD and COD respectively) is discharged by most of the distilleries in local water bodies without any treatment. Since most of the distilleries are in rural areas and attached to sugar factories the effluent discharge pollutes the water and environment and is very harmful to the fields and animals.

Around four km away from my house in Phaltan is one such distillery. During our monsoon (September-October) the winds come from easterly direction over the distillery and this foul-smelling wind over the distillery effluent is really troublesome.

So we started thinking of detoxifying distillery effluent and thought of using solar energy to treat this waste and developed a scheme by which a suitable photocatalyst when mixed with diluted effluent and exposed to sun could reduce the color and the chemical oxygen demand.

After the lab experiments we set up a solar detoxification plant in 2002 to clean 100 liters of diluted effluent per day. (Pictured left). The process made the water quite transparent, completely removed the smell, and drastically reduced COD and BOD. We also tested this treated water on crops and found it to be beneficial to their growth.

We tried to sell this technology to lots of distilleries, but they thought the price of photocatalyst to be high and also did not want to spend any money on treating the effluent since they could easily discharge it at night in the water bodies like canal, rivers etc. With laxness and corruption in local pollution boards there is not too much incentive to go for such technologies.

Areas for future research and development (R&D)

R&D on water is a very vast subject. I am outlining the areas that we have touched in our work. Thus the following challenges exist:

(1) Study and duplicate the reverse osmosis (RO) mechanism of mangroves and sea grasses. This may help design better RO plants.

(2) Design and build an experimental cloud suction plant.

(3) Dew condensation for potable water production should be the strategy adopted for coastal areas. Our estimates show that almost 50% of India's total drinking water requirements can be met by dew condensation strategies as outlined in our paper.

(4) Ship-based offshore dew condensation systems should be studied. The deep cold sea water can be used for dew condensation and the fresh water produced can be stored in huge plastic floating bags. These can easily be towed to the shore for delivery of fresh water.

(5) Large scale deployment of soil water evaporation units can be useful in increasing green cover in arid regions and can be useful for horticulture plantations.

(6) Large scale deployment of rainwater harvesting with SWP should be installed in rural schools. This could be funded by CSR funds. We are setting up one unit in Phaltan rural school.

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