SOME INTERESTING ASPECTS OF WATER, WITH SPECIAL REFERENCE TO NUCLEAR DESALINATION

*Inam-ur-Rahman**

ABSTRACT

A brief review is given of the formation, importance, resources and some unique characteristics of water. A reference has been made about the available water-resources of Pakistan and urgent need of acquiring additional water-resources in the country. Importance of water for energy-production and energy for acquiring additional water-resources is mentioned.

Attractive features and feasibility of nuclear desalination, using dual-purpose nuclear power plants are discussed. Criteria for selection of suitable reactor-type and desalination process are discussed for desired water-to-power ratios. The world-wide growth of desalination-capacity, using various desalination- processes are listed.

INTRODUCTION

Some verses from the Holy Quran about water are worth considering here:

……………We made from water every living thing.

[Sura Anbiyaa(21:30)]

.... The companions of the fire will call to the companions of the garden. "Pour down to us water or anything that God doth provide for your sustenance". They will say: "Both these things hath God forbidden to those who rejected Him".

[Sura Araf(7:50)]

.... And further, thou seest the earth barren and lifeless, but when We pour down water on it, it is stirred (to life), it swells, and it puts forth every kind of beautiful growth.

[Sura Hajj (22 :5)]

.... The son replied: "I will betake myself to some mountain. It will save me from the water". Noah said: "This day nothing can save from the command of God, any but those on whom He hath mercy.

[Sura Hud (11:43)]

FORMATION AND DISTRIBUTION OF WATER

This is part of the question how the earth was formed. The materials that make up the earth included plenty of oxygen and hydrogen. As the earth cooled and became solid, these elements combined to form water. The water so formed was trapped in rocks and was released slowly, to fill up the depressions now forming the oceans.

Distribution

About 70% of the earth's surface is covered with water. The total quantity in the oceans, ice caps, rivers, lakes, underground and atmosphere is estimated to be around 1.4 billion cubic kilometers. The break-up is as follows:

Oceans and inland seas .... ~ 97.21%

Ice-caps and glaciers .... ~ 2.16%

Surface and underground .... ~ 0.63%

Atmosphere .... ~ 0.001%

Total: =100%

IMPORTANCE AND REQUIREMENTS OF WATER

All living things (i.e. zoological and botanical) cannot survive without water, except perhaps the computer viruses!

Great civilizations had their beginnings where water-supplies used to be plentiful, and had fallen when these supplies disappeared. As water is essential for life, there have been instances where people have killed one another for a glass of water!

5 per cent of the land contains half the population of the world, due to uneven distribution of water.

There is as much water on earth today as there ever was and ever will be. The same water that was dirty is purified by the great water-cycle, over and over again, since the

* Scientist Emeritus, Pakistan Institute of Engineering & Applied Sciences (PIEAS), P O Nilore, Islamabad, Pakistan.

formation of the water body. If the rain fell uniformly all over the earth, it would receive 26 inches a year. Every glass of water that we drink contains water-molecules that had been used countless times before. Part of the water that you used today might have been used by Pharaoh or perhaps Adam thousands of years ago!

For a balanced diet and reasonable living, more than 2000 gallons is required per person per day:

Diet.......................................	~2000 gallons
Domestic & Industrial................	~200 gallons

As the total usable quantity of water is fixed and the population is increasing, additional water resources are needed for about 80 million people added annually in the existing world-population.

SOME SPECIAL CHARACTERISTICS OF WATER

Water has greatest solubility for most of the impurities —— it dissolves the impurities and dirt, purifies/cleans everything and becomes polluted, to be purified by the water-cycle. It is said that water cleans the body, just as prayers and repentance purifies the soul!

The specific heat of water is one of the highest. This helps in maintaining the temperature of all living beings at a manageable level. If the specific heat of water was low, like metals, the blood would have been boiling due to absorption of **2.5 million calories** daily produced due to our diet.

Water-density is highest at 4°C and decreases as temperature falls down or goes up. This is responsible for preserving aquatic life in the coldest ocean.

Very high values of heat of vaporization (540 calories) and heat of fusion (80 calories) are responsible for prevention of floods and water-losses due to vaporization.

WATER FOR ENERGY AND ENERGY FOR WATER!

Energy is essential for economic development of a country. As a matter of fact, per-capita energy-consumption is the best index to gauge the standard of living of a country. Most of the existing energy-sources would not have been possible, without water.

On the other hand, for production of fresh water from oceans, large inputs of energy are required. Additional water-resources from more than 99% of the untapped water (Oceans & Ice-caps) have become absolutely necessary, keeping in view the increasing world-population and pollution of the existing water resources.

Let us review the variety of ways in which water becomes the source of energy. In the next section on nuclear desalination, the use of energy for production of fresh water will be discussed. Besides, energy is needed for separation of hydrogen & deuterium, which are the sources of chemical and nuclear energy.

Energy Due To Water Movement

- Hydro Energy
- Tidal Energy
- Wave Energy

Energy Due to Chemical & Nuclear Reactions

- Hydrogen Energy
  (chemical reaction, based on combustion of hydrogen)
- Fusion Energy
  (nuclear reaction, involving D-D reaction)

Miscellaneous Uses of Water in Energy-Production

Water is used as an essential item for electrical energy-production as a conversion medium in conventional and nuclear power plants. In nuclear power plants, water is also used as a coolant, moderator and shielding material.

Geothermal energy cannot be utilized, effectively, without water. A geothermal power station utilizes the high-temperature, high-pressure steam, on lines similar to the fossil and nuclear power plants.

NEED FOR WATER-RESOURCE PLANNING FOR PAKISTAN

Keeping in view the increasing population and diminishing water-resources (due to pollution, scarce rainfalls, decreasing river-discharges, silting in rivers and dams) additional water resources are required. In Terbella alone, silting is estimated at a rate of

6 lacs tons daily ——— this would require 50 thousand trucks daily to remove the silt. Water-resource planning is extremely necessary and deserves top priority. This is obvious from the following data:

Total water available in Pakistan = 142 maf
(1 maf = 3.26 10^{11} U.S. gallons)

Total water utilized annually = 65 maf
(the balance is discharged to the ocean, evaporated, polluted or wasted)

Per-capita daily water availability:

$$\frac{65 \text{ maf/year} \times 3.26 \times 10^{11} \text{gallons/mat}}{140 \times 10^{6} \times 365 \text{ person - days/year}}$$

= 430 gallon/person-day!

Even if all the available water is used fully the per capita water availability works out to be around 430 gallons per person per day. This is about 50% of the standard daily water requirements!

Immediate steps are hence essential for effective utilization of the existing resources and finding ways & means of alternate sources of water. These include:

- Attitude towards water-use;
- Training & education and appropriate technology-input for economic use of water in farming, industry, municipal & household use of water;
- Construction of small dams and water-reservoirs, to avoid wasteful flow of water to the oceans;
- Desalination technologies, for exploitation of huge water available in oceans i.e. 97% of total.

NUCLEAR DESALINATION FOR PROJECTED WATER REQUIREMENTS

Attractive Features of Nuclear Desalination

Nuclear energy is now a well-established source of energy and is used to produce electricity in 30 Countries. It provides 6% of total global energy and 17% of global electricity. In some countries, more than 70% of electrical energy is nuclear. At the end of the year 2000, 439 nuclear power reactors with a total capacity of 352 Gwe were in operation. Total capacity of nuclear reactors used for co-generation of hot water/steam for district heating, seawater desalination and other industrial processes is about 5 GW_{th}.

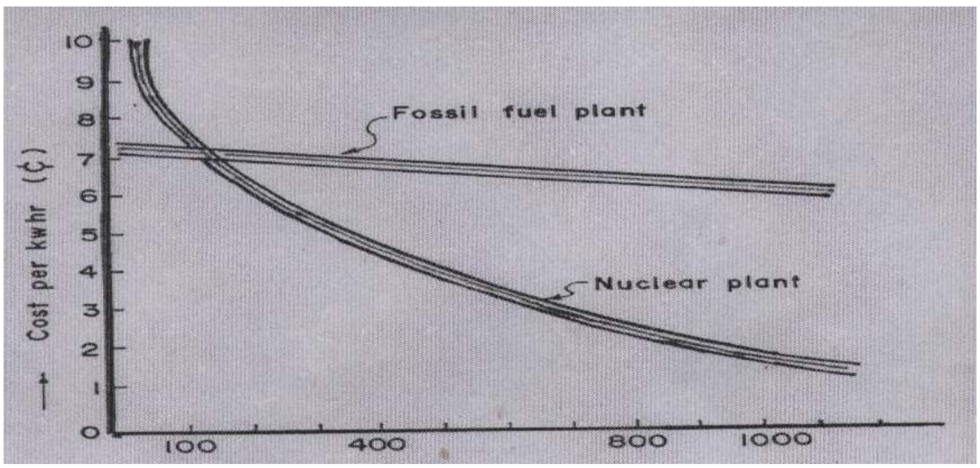


Figure - 1: Nuclear Plant-Size to Energy-Cost Ratio

The first paper regarding the feasibility of using nuclear energy for distilling seawater by R.P. Hammond of ORNL, U.S.A. appeared in 1962 ("Large scale reactors may distill sea water economically" Nucleonics 20 (12):45-49, 1962). Various reasons put forward in the paper are summarized here:

1. Nuclear energy cost (unlike conventional energy cost) is very sensitive to the plant size. Larger the nuclear power plant, lower is the cost per kwhr. Hence if energy and water requirements of a region are pooled together, the plant-size will become larger, reducing thereby the cost of electricity, as well as water. This is shown in Figure - 1.

2. Nuclear power plants have relatively lower thermal efficiency, as compared to conventional power plants. Hence, for the

same electrical energy output, the nuclear power plant will have larger amount of waste-heat for dumping in oceans and rivers.

3. While high-quality steam is required tob) produce electrical energy, lower-quality steamc) is needed for desalination. At present, the maximum brine temperature used for desalination is about 250°F. At higher temperature, the formation of scale and corrosion of heat-transfer surfaces drastically reduce the distillation-plant efficiency. Most of the residual steam rejected by the turbine can thus, be used for desalination purposes.

The usefulness of a dual-purpose plant can be illustrated by considering three separate plants i.e. a 100 MOD water-only plant; a 200 MWe power-only plant; and a dual-purpose plant producing 100 MOD and 200 Mwe. The dual-purpose plant would need about 40% less energy, as compared to the two single-purpose plant. See Figure - 2.

would yield higher power-to-water ratio, while medium-temperature reactors (pressurized water reactors) would give higher water-to-power ratio.

Revival of interest in the use of nuclear energy for desalination (besides economic factors) is also due to conservation of fossil fuels and protection of environment,

VARIOUS DESALINATION TECHNOLOGIES

The desalination technologies that are commonly used in various plants operating in the world are mainly.

- Multi-stage Rash Distillation Process (MSF)
- Multi-Effect Distillation Process (MED)
- Reverse Osmosis (RO)

Coupling of the selected nuclear reactor with a suitable desalination-process requires

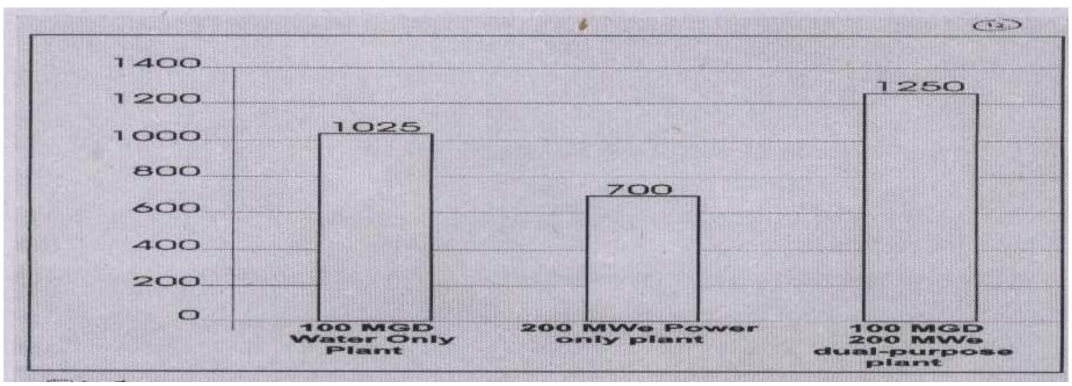


Figure - 2: Thermal Energy Requirements for Three Plants Using Water-Cooled Reactors

Some other considerations for dual-purpose nuclear plants are listed here:

a) Site-selection for a dual-purpose plant involves more work and studies, as compared to a single-purpose water or power-only plant. Things like availability of raw feed-water, disposal/management of concentrated brine, storage and conveyance-cost of product water should be considered while making selection of the site.

b) Selection of the nuclear reactor type is strongly dependent on applications of the reactor. For heat-applications, specific temperature-requirements vary greatly. They range from about 100°C for desalination to 1000°C for production of hydrogen. High-temperature reactors (Gas- cooled Reactors)

thorough investigations. While the multi-stage flash-distillation process appears to be the most favoured process for large nuclear desalination plants, there appears to be some shift recently for reverse-osmosis and multi-effect distillation processes.

Figures-3&4 show percentage of the operating desalination plants using various technologies and total, as well as country-wise, installed desalination capacity.

Tables-1&2 outlines some salient characteristics of commercial desalination processes, as well as the capacity and desalination techniques of the 10 largest seawater-desalination plants.

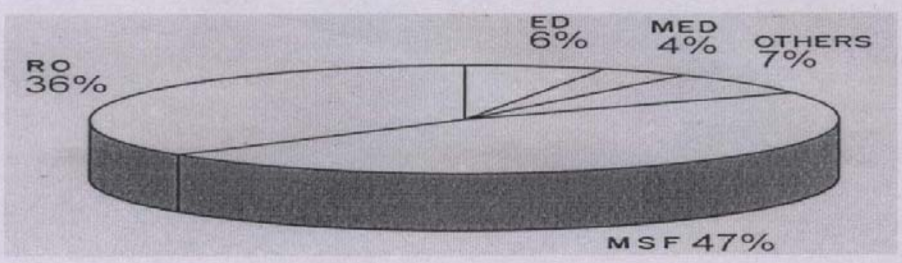


Fig. 3 (a)

Desalination plants with the capacity greater than 100 m^3/d using various technologies.

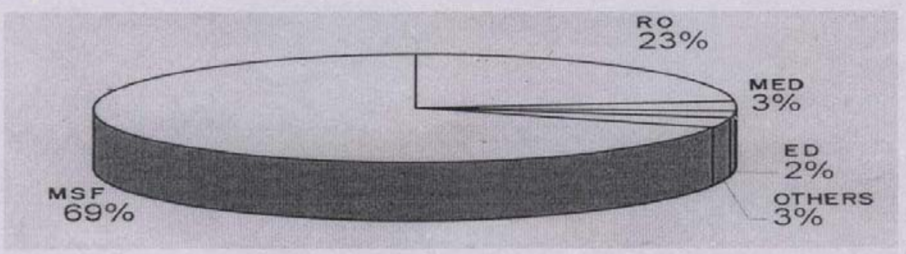
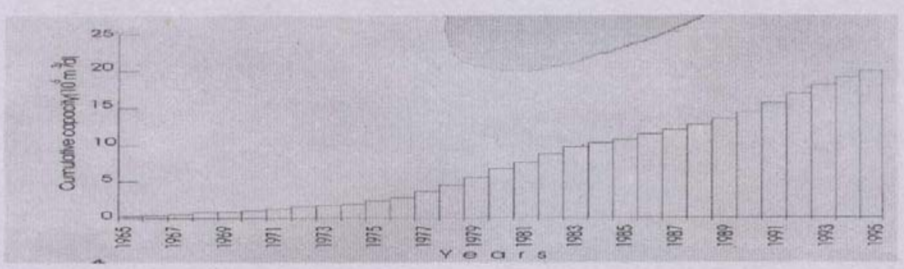


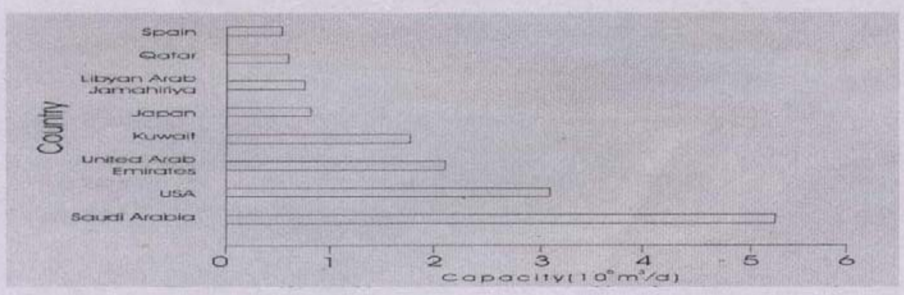
Fig. 3 (b)

Desalination plants with the capacity greater than 4000 m^3/d using various technologies.



Total installed desalination capacity

Fig. 4 (a)



Desalination capacity by country

Fig. 4 (b)

Figure – 3(a) & 3(b) and 4(a) & 4(b)

Table -1: Some Salient Characteristics Of Commercial Desalination Process

Process	Characteristics					
	Possible Unit Size m^3/d	Limiting factor	Experience Available	Maintenance Requirement	Energy Consumption	Top brine Temperature °C
MSF Present Future	50,000 75,000 ?	Vacuum System	Highest	Low	High? (thermal)	85-130
MED Present Future	20,000 30,000	Plant Reliability	High	Low	Medium ? (thermal)	55-130
RO Present Future	10,000 15,000 (small-large)	Pumps	Medium	High	Low (electrical)	Ambient

Table - 2:World's 10 Largest Seawater Desalination Plants

Sr. No.	Name of the Plant, Capacity and Desalination Technique.		
1	Al Jobail, Saudi Arabia	1,173,000 m^3/d (310 mgd)	46 MSF Units 15RO Units
2	Jebel Ali Dubai	869,000 m^3/d (230 mgd)	28 MSF Units
3	Taweelah Dubai	806,000 m^3/d 213 mgd)	16 MSF Units
4	DohaKuwait	695,000 m^3/d (184 mgd)	23 MSF Units
5	Az-Zour South Kuwait	482,000 m^3/d (mgd)	16 MSF Units
6	Shuaiba, Saudi Arabia	454,000.m^3/d (120 mgd)	10 MSF Units
7	Al Khobar, Saudi a Arabia	450,000 m^3/d (119 mgd)	18 MSF Units
8	Jeddah Saudia Arabia	420,000 m^3/d (111mgd)	18 MSF Units 10 RO Units
9	Umm Al Nar Abu Dhabi	400,000 m^3/d (106 mgd)	16 MSF Units
10	Yanbu Saudia Arabia	382,000 m^3/d (101 mgd)	9 MSF Units 15 RO Units

ALLOCATION OF COST TO WATER AND POWER IN DUAL PURPOSE NUCLEAR PLANTS

In a dual-purpose plant, the cost of water or power could be made to appear very attractive by assigning all the benefit of the dual-purpose plant to any one of the two products. The total annual expenditure C_a is equal to:

$$C_a = {}_{CE} E_a + {}_{CW} W_a$$

${}_{CE}$ = Cost per KWhr of electricity
E_a = KWhr produced per year
${}^{C}{}_{W}$ = Cost per m^3 of water
W_a = M^3 of water produced per year.

One of the two products could be subsidized by allocating higher prices to the other, as shown in Figure-5.

METHODS OF COST CALCULATION

Cost of water appears to be very attractive if all the benefit of the dual-purpose nuclear plant is assigned to

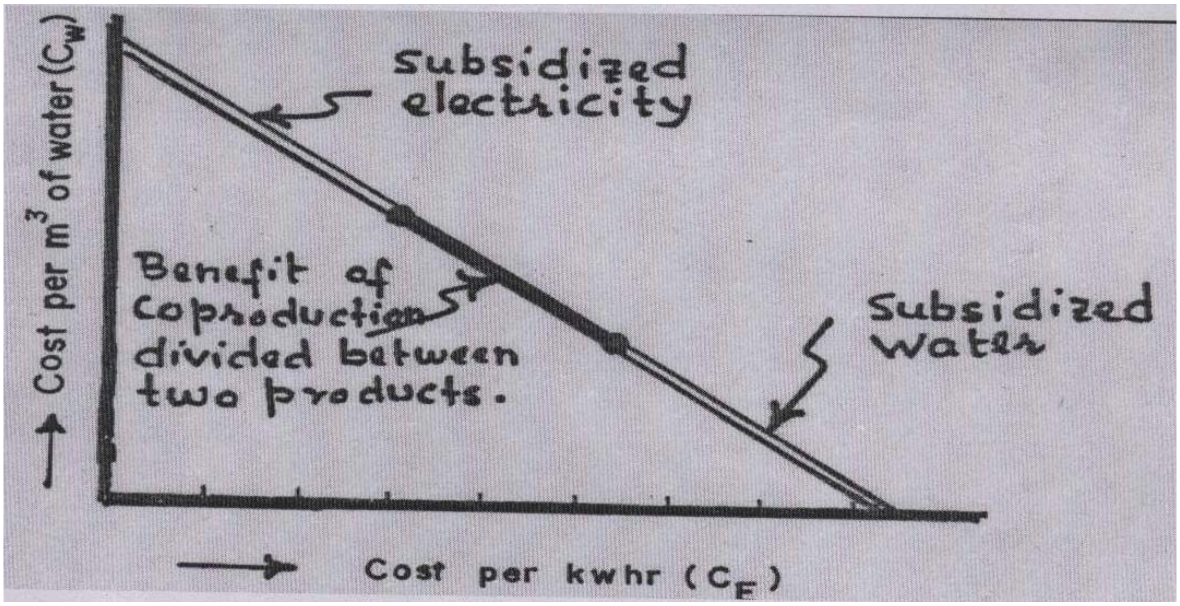


Figure - 5: Allocation of Cost to Water and Power.

water. For example, if:

C_D = Annual Cost of a dual-purpose plant producing P Mwe and W MGD
C_W = Annual minimum cost of a water-only plant, producing W MGD
C_P = Annual minimum cost of a power-only plant, producing P MWe

In case all the benefit of the dual-purpose plant is given to water, the annual cost assigned to water would be:

$$= (C_D - C_P)$$

On the other hand if all the benefit is to be assigned to power, the annual cost assigned to power would be:

$$= (C_D - C_W)$$

Even if the economic benefit is proportionately shared by power and water, the cost of both the products would be significantly lower than the minimum cost for water and power plants, i.e. C_p

Cost allocated to power $= C_D \frac{C_P}{(C_P - C_W)}$

.... This is smaller than Cp

Cost allocated to water $= C_D \frac{C_W}{(C_P - C_W)}$

.... This is smaller than C_W

Normally, when a new item is produced in a multi-purpose plant (in this case water), the benefit of the plant is given to the new product to make it appear more attractive from cost-economics point of view. This should of course be done without increasing the cost of other products. The cost of water from a large nuclear dual-purpose plant becomes competitive in water-scarce areas if the annual cost assigned to water is (C_D - C_p).