A dual purpose nuclear power plant using FBNR

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ABSTRACT

The adequacy of nuclear reactor FBNR for nuclear desalination is investigated. The importance of nuclear desalination to supply the increasing need of potable water to satisfy the requirements of growing world population is analyzed. Various methods of sea water desalination are described, and the adequacy of FBNR as a double purpose nuclear reactor to produce simultaneously electricity and desalinated water are demonstrated. .

1. INTRODUCTION

The potable water worldwide is becoming increasingly scarce. The usable portion of all water resources is only about 200 000 km^3 of water, that is less than 1% of all freshwater and only 0.01 per cent of all water on Earth. Nuclear desalination using FBNR nuclear reactor can help solve this problem that is afflicting humanity. Nuclear desalination is defined to be the production of potable water from sea water in a facility in which a nuclear reactor is used as the source of energy for the desalination process. Nuclear desalination is technically feasible, economically viable and is sustainable solution to meet the future water demands.

The FBNR nuclear reactor may be dedicated solely to the production of potable water, or may be used for the generation of electricity and the production of potable water, in which case only a portion of the total energy output of the reactor is used for water production. The desalination of seawater using nuclear energy is a feasible option to meet the growing demand for potable water. Over 150 reactor-years of operating experience on nuclear desalination have been accumulated worldwide.

A dual purpose plant or co-generation plant consists of a nuclear reactor and a desalination system coupled to the reactor, sharing common systems and facilities, producing both, fresh water and electricity. The dual purpose plant can produce desalinated water at 30% to 40% lower cost compared to a single purpose plant.

The International Atomic Energy Agency (IAEA) has started a program on nuclear desalination since 1998 and has been providing guidebooks, technical documents, and computer programs on nuclear desalination as well as technical assistance through the framework of technical co-operation programs.

2. INNOVATION IN NUCLEAR ENERGY

More than half a century has passed since peaceful use of nuclear energy began. Recently, international cooperation activities, such as the Generation IV International

Forum (GIF) initiated by US Department of Energy and the International Project of Innovative Nuclear Reactors and Fuel Cycles (INPRO) initiated by IAEA, have motivated the nuclear scientists and technologists around the world to search for a new generation of innovative nuclear reactors where practically "total safety" is achieved. The advent of innovative nuclear reactors is a shift in paradigm. It is based on a new safety philosophy, making the occurrence of accidents such as TMI and Chernobyl impossible.

There are two sources of heat generation in a nuclear reactor. One is the heat produced by nuclear fission and the other by decay of radioactive materials that are produced by the fission of nuclear fuel. The reactor safety of innovative reactors promotes inherent safety philosophy meaning that the law of nature should govern the safety of the future reactors and not the manmade safety systems. For example, the safety of the proposed reactor namely the FBNR is obtained by utilizing the law of gravity that is inviolable, and the cooling of residual heat due to the decay of fission products is achieved by natural heat convection.

3. DESCRIPTION OF FBNR

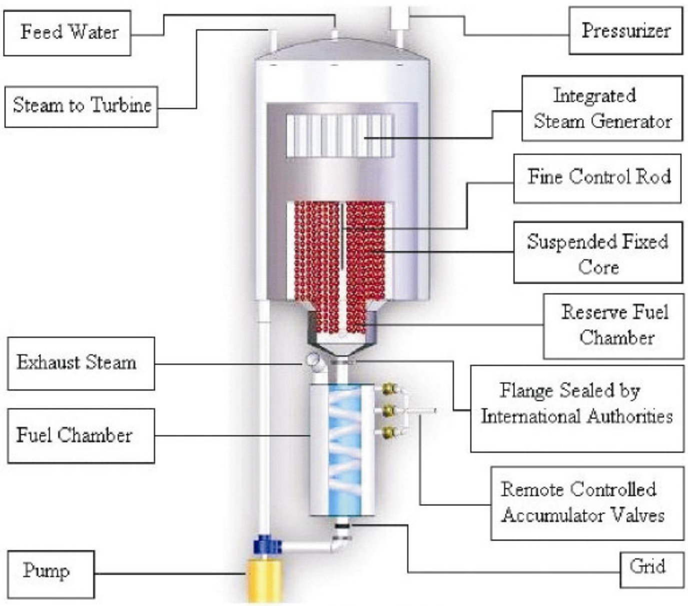
The Fixed Bed Nuclear Reactor (FBNR) is a small reactor (70 MWe) without the need of on-site refueling. It utilizes the PWR technology. It has the characteristics of being simple in design, modular, inherent safety, passive cooling, proliferation resistant, and reduced environmental impact.

The FBNR fuel chamber is fuelled in the factory. The sealed fuel chamber is then transported to and from the site. The FBNR has a long fuel cycle time and there is no need for on-site refueling. The reactor makes an extensive use of PWR technology. It is an integrated primary system design.

The reactor as shown in the schematic figure, have in its upper part the reactor core and a steam generator and in its lower part the fuel chamber. The core consists of two concentric perforated zircaloy tubes of 31 cm and 171 cm in diameters, inside which, during the reactor operation, the spherical fuel elements are held together by the coolant flow in a fixed bed configuration, forming a suspended core. The coolant flows vertically up into the inner perforated tube and then, passing horizontally through the fuel elements and the outer perforated tube, enters the outer shell where it flows up vertically to the steam generator. The reserve fuel chamber is a 60 cm diameter tube made of high neutron absorbing alloy, which is directly connected underneath the core tube. The fuel chamber consists of a helical 30 cm diameter tube flanged to the reserve fuel chamber that is sealed by the national and international authorities. A grid is provided at the lower part of the tube to hold the fuel elements within it. A steam generator of the shell-and-tube type is integrated in the upper part of the module. A control rod can slide inside the centre of the core for fine reactivity adjustments. The reactor is provided with a pressurizer system to keep the coolant at a constant pressure. The pump circulates the coolant inside the reactor moving it up through the fuel chamber, the core, and the steam generator. Thereafter, the coolant flows back down to the pump through the concentric annular passage. At a flow velocity called terminal velocity, the water coolant carries the 15 mm diameter spherical fuel elements from the fuel chamber up into the core. A fixed suspended core is formed in the reactor. In the shut down condition, the suspended core breaks down and the fuel elements leave the core and fall back into the fuel chamber by the force of gravity. The fuel elements are made of UO_2 micro spheres embedded in zirconium and cladded by zircaloy.

Any signal from any of the detectors, due to any initiating event, will cut-off power to the pump, causing the fuel elements to leave the core and fall back into the fuel chamber, where they remain in a highly subcritical and passively cooled conditions. The fuel chamber is cooled by natural convection transferring heat to the water in the tank housing the fuel chamber.

The pump circulates the water coolant in the loop and at the mass flow rate of about 220 kg/sec, corresponding to the terminal velocity of 1.50 m/sec in the reserve fuel chamber, carries the fuel elements into the core and forms a fixed bed. At the operating flow velocity of 7.23 m/sec, corresponding to the mass flow rate of 1060 kg/sec, the fuel elements are firmly held together by a pressure of 0.188 bars that exerts a force of 27.1 times its weight, thus forming a stable fixed bed. The fixed bed is compacted by a pressure of 1.3 bars. The coolant flows radially in the core and after absorbing heat from the fuel elements enters the integrated heat exchanger of tube and shell type. Thereafter, it circulates back into the pump and the fuel chamber. The long-term reactivity is supplied by fresh fuel addition and possibly aided by a fine control rod that moves in the center of the core controls the short-term reactivity. A piston type core limiter adjusts the core height and controls the amount of fuel elements that are permitted to enter the core from the reserve chamber. The control system is conceived to have the pump in the "not operating" condition and only operates when all the signals coming from the control detectors simultaneously indicate safe operation. Under any possible inadequate functioning of the reactor, the power does not reach the pump and the coolant flow stops causing the fuel elements to fall out of the core by the force of gravity and become stored in the passively cooled fuel chamber. The water flowing from an accumulator, which is controlled by a multi redundancy valve system, cools the fuel chamber functioning as the emergency core cooling system. The other components of the reactor are essentially the same as in a conventional pressurized water reactor.



Schematic Design of FBNR

4. WATER NEEDS OF THE WORLD

"Clean fresh water is indispensable for the existence of mankind. It is a basic need for human life, food production and economic development. Although the current usage of water in the industrialized countries may give an impression that fresh water is inexhaustible, recent statistics show that currently 2.3 billion people live in water-stressed areas and among them 1.7 billion live in water-scarce areas, where the water availability per person is less than 1000 m^3/year." [1]

"The total volume of water on Earth is about 1 400 million km^3 of which only 2.5%, or about 35 million km^3, is freshwater. Most freshwater occurs in the form of permanent ice or snow, locked up in Antarctica and Greenland, or in deep groundwater aquifers. The principal sources of water for human use are lakes, rivers, soil moisture and relatively shallow groundwater basins. The usable portion of these sources is only about 200 000 km^3 of water – less than 1% of all freshwater and only 0.01 per cent of all water on Earth." [2]

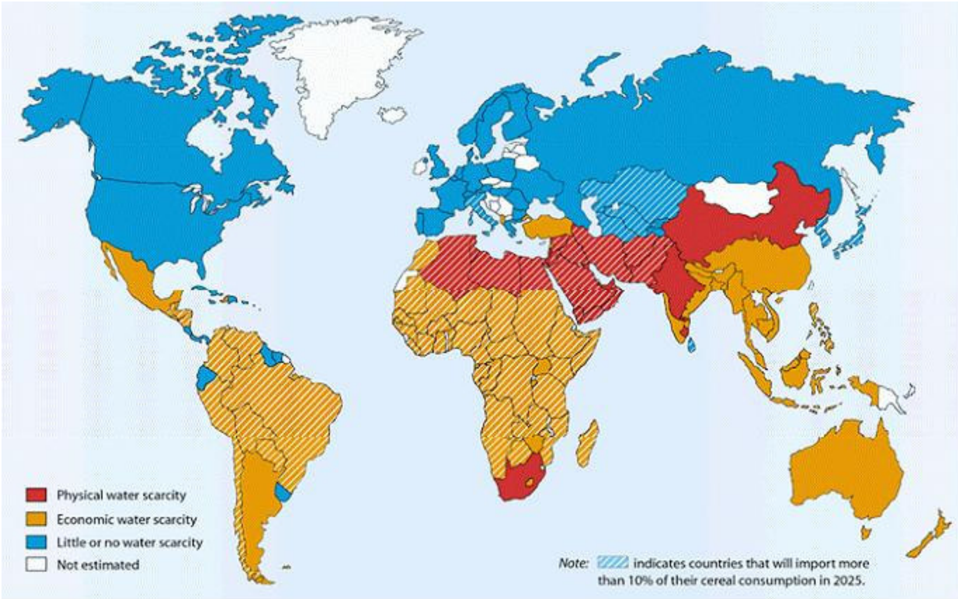


Figure 1 - Regions of the world facing water shortages.

"In Figure 1 countries which will face "economic water shortages" (i.e. inadequacy of supply and demand) are shown and regions with diagonal lines are the ones which will import more than 10% of their cereal consumption in 2025. It should be recalled that to produce 1 ton of cereals one requires 1000 m^3 of water." [3]

If current trends persisted, by 2020 water use is expected to increase by a further 40%. United Nations Environment Programme has shown that the share of the world's population in countries undergoing moderate or high water stress could rise to two thirds by 2025.

Water related problems are a global issue and every year new countries are affected. To solve this problem, additional freshwater production capability must be developed. Due the abundance of seawater, desalination is a good option offering water otherwise not accessible.

5. IMPORTANCE OF WATER DESALINATION

Desalination is a process of separating dissolved salts from water, to obtain fresh water with low salinity. It is an energy intensive process, so the increasing demand for water creates a collateral demand for increased energy production. Fossil fuel-powered plants have mainly been utilized, but over the long term, desalination with fossil energy sources would not be compatible with sustainable development, fossil fuel reserves are finite and the future uncertainty price of it are factors to be considered. Furthermore, the combustion of fossil fuels produce large amounts of greenhouse gases and toxic emissions. In this context, nuclear desalination appears to be a technically feasible, economically viable and sustainable solution to meet the future water demands.

"Nuclear desalination is defined to be the production of potable water from sea water in a facility in which a nuclear reactor is used as the source of energy for the desalination process. Electrical and/or thermal energy may be used in the desalination process. The facility may be dedicated solely to the production of potable water, or may be used for the generation of electricity and the production of potable water, in which case only a portion of the total energy output of the reactor is used for water production. In either case, the notion of nuclear desalination is taken to mean an integrated facility in which both the reactor and the desalination system are located on a common site and energy is produced on-site for use in the desalination system. It also involves at least some degree of common or shared facilities, services, staff, operating strategies, outage planning, and possibly control facilities, and seawater intake and outfall structures." [4]

"Nuclear power is a proven technology, which has provided more than 16% of world electricity supply in over 30 countries. More than ten thousand reactor-years of operating experience have been accumulated over the past 5 decades. In recent years, the option of combining nuclear power with seawater desalination has been explored to tackle water shortage problem. The desalination of seawater using nuclear energy is a feasible option to meet the growing demand for potable water. Over 150 reactor-years of operating experience on nuclear desalination have been accumulated worldwide." [5]

Nuclear reactors provide heat in a large range of temperatures, which allows easy adaptation for any desalination process and some nuclear reactors supply waste heat at ideal temperatures for desalination. There are no specific nuclear reactors for desalination. Any reactors capable of providing electrical and/or thermal energy can be coupled to an appropriate desalination process.

Desalination was previously regarded as a prohibitively expensive solution for the increasing water demand, but recently cost reduction due technological innovations have led to a more favorable and competitive option against other water treatment approaches.

6. DESCRIPTION OF WATER DESALINATION METHODS

The desalination processes can be divided into two types: processes using electricity and processes using heat. The first type is composed mainly by distillation processes, as MSF (multi stage flash) and MED (multi-effect distillation). And the second, by membrane processes, electrodialysis and vapour compression, which is a distillation process but uses electricity.

Many desalination technologies have been proposed based on different principles of separation, but not all of them reached commercial operation. The commercial seawater desalination processes, which are proven and reliable for large-scale production are MSF, MED and RO (reverse osmosis). "Combining distillation processes with membrane processes into hybrid systems has certain merits where the specific advantages and disadvantages of each enable mutual compensation. Low temperature waste heat from nuclear research reactors and power plants is an abundant source of low cost energy for those desalination technologies, which can operate effectively at low temperature. Such a system is Low Temperature Evaporator (LTE) which operates at temperatures close to the reject heat temperature of a typical power plant [6]."

6.1 MULTI STAGE FLASH

“About 60% of the world’s desalting capacity comes from MSF plants. This has been one of the leading desalination processes, because of operational simplicity, proven performance and availability of standard designs and equipment. MSF plants produce practically pure water having about 5–25 ppm TDS (Total Dissolved Solids, is an expression for the total content substances dissolved in a liquid) from sea water containing 35 000 to 45 000 ppm TDS. It is advantageous in large capacity ranges where thermal energy in the form of low pressure steam is available.” [4]

In the MSF process, the seawater is heated to the maximum brine temperature in the brine heater and introduced to another container known as a "stage", where the surrounding pressure is below the saturated vapour pressure of the brine at that temperature. The sudden lower pressure causes the brine to boil so quickly as to flash into steam. But only a small portion of this water is converted into steam, the remaining water is sent through a series of additional stages, each of them having a lower pressure than the previous stage. The vapour in each stage condenses on the outer surface of the feed stream tubes, giving its latent heat to the incoming sea water flowing inside the tubes, thus the feed stream is heated progressively in each stage before passing through the brine heater used to feed the first stage. The hot condensate also passes through all the stages and cools itself while flashing a portion into steam, then it is collected as product fresh water.

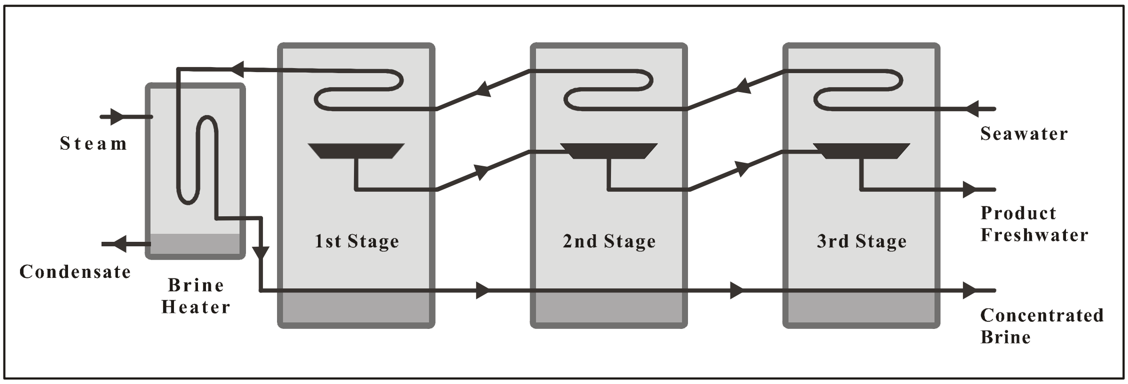


Figure 2 - Simplified MSF system

“Sea water contains sulphate, bicarbonate, calcium and magnesium ions, which contribute to scaling. Formation of scale leads to a sharp fall in overall heat transfer performance and production rate. In order to control the alkaline scaling tendency, before reaching the brine heater, the sea water is first sent to a chemical pre-treatment system. Acid or chemical additives are added to prevent the formation of alkaline cruds in the heat transfer tubes. Then the water is de-aerated to reduce the dissolved oxygen and CO_2 to minimize corrosion risk, improving heat transfer performance.” [1,4]

“Although, most of the desalination plants in the world are of MSF type, the technology has reached its limits and is gradually being replaced by RO or MED plants which have a much higher potential for further development and which consume less energy” [1].

6.2 MULTI-EFFECT DISTILLATION

The MED process has been used for industrial distillation for a long time. It is the oldest large scale evaporative process used for the concentration of chemicals and food products, and it was the first process used for producing significant amounts of desalted water from sea water. However, its large scale application to desalination began only during the past two decades. The process produces around 5–25 ppm TDS product water quality from 35 000 to 45 000 ppm of sea water. [4]

In the MED process, the seawater is boiled in the first vessel, as the boiling point of water decreases as pressure decreases, the vapour from the first vessel condenses in the second and its heat is used to boil the sea water in the second evaporator, which has a lower pressure than the previous. The seawater passes to the next effect and the vapour from the previous effect boils it, repeating the process. Increasing the number of stages, increase the water production, but also causes a higher investment, so an optimum number must be determined depending on the plant specifications.

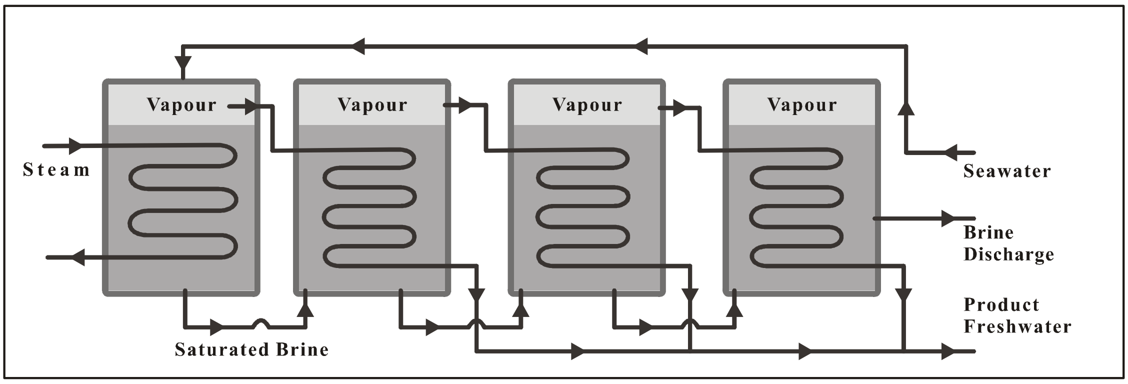


Figure 3 - Simplified MED system

Currently, the two types of MED processes most used for large scale desalination are: the HT-VTE (high temperature vertical tube evaporator) also known as VTE and the LT-HTME (low temperature horizontal tube multi-effect) or HTME. The main difference between them is the configuration of the evaporation tubes and the maximum brine temperature, which directly affects the materials used.

“Comparison between HTME and VTE-MED plants indicated that HTME plants have better heat transfer in the temperature range 20–70^{0}C, while VTE plants have better heat transfer above 70^{0}C” [6].

“The HTME process is thermodynamically superior over MSF, its maximum brine temperature is about 70^{o}C. Due the low temperature operation, the risk of corrosion and scaling is reduced, thus pre-treatment is reduced and expensive corrosion resistant materials are not needed. The possibility of using more economic materials, such as aluminum alloy, enables the increase of the heat transfer area per ton of water produced for the same investment cost. As result, a very low temperature drop per effect is needed (1,5 – 2,5^{o}C), enabling a larger number of effects.” [7]

6.3 REVERSE OSMOSIS

“Reverse osmosis is by far the most widespread type of membrane based desalination process. Energy consumption is the lowest among all options for seawater desalination, making it most cost efficient in regions with high energy cost” [8]. “The salt content of the permeate water from single stage RO plants is normally within the permissible limit of drinking water quality. For very pure water of around 20–50 ppm, a second membrane stage is necessary" [4].

A semi permeable membrane is placed between two compartments. The membrane allows the solvent to flow through it, but does not allow the solute to move from one compartment to the other. To obtain the equilibrium, the solvent from areas of low solute concentration moves to areas of high solute concentration. Areas with low concentration become more concentrated and areas with high concentration will decrease solute concentration, this process is called osmosis. In the reverse osmosis process, a pressure (commonly ranging from 55 to 68 bar [8]), is applied to the compartment with high concentration of solute, part of the seawater (30 to 40% [6]) permeates thought the membrane, producing freshwater, the remaining concentrated water is sent back to the sea. The product water generally needs some type of post treatment, such as: pH adjustment by dosing soda ash or lime, removal of dissolved gases and disinfecting.

"RO membranes are made of natural or synthetic polymer. It should possess good selectivity, low resistance to water flow and adequate chemical and mechanical stability. The first desalination membranes were made of cellulose acetate and used for brackish water. Current seawater RO membranes are based on polyamide. With the development of thin film composite (TFC) membranes, the skin thickness has been reduced to a few hundred Å, giving high permeate flux at low pressure without sacrificing salt rejection" [4]. The number of desalination plants using RO has been increasing, due the rapid improvements in RO technology and associated equipment.

6.4 MECHANICAL VAPOR COMPRESSION

"The mechanical vapor compression is a distillation process that requires only electric power for operation. It is a simple, reliable process and produces around 5-25 ppm TDS product water quality" [4]. Its efficiency is governed by the effectiveness of the heat transfer surface, the compressor efficiency and the effectiveness of the heat recovery from the rejected brine and produce water steams.

A steam compressor is used to maintain a pressure difference between the two sides of the heat transfer tubes. Seawater is pumped to the low pressure side, it heats and boils. Then, the vapour goes to the compressor, where it is heated via the heat of compression and is delivered to the high pressure side of the heat transfer tubes. There, the vapour condenses and gives up its latent heat to boil the incoming seawater on the other side of the tube.

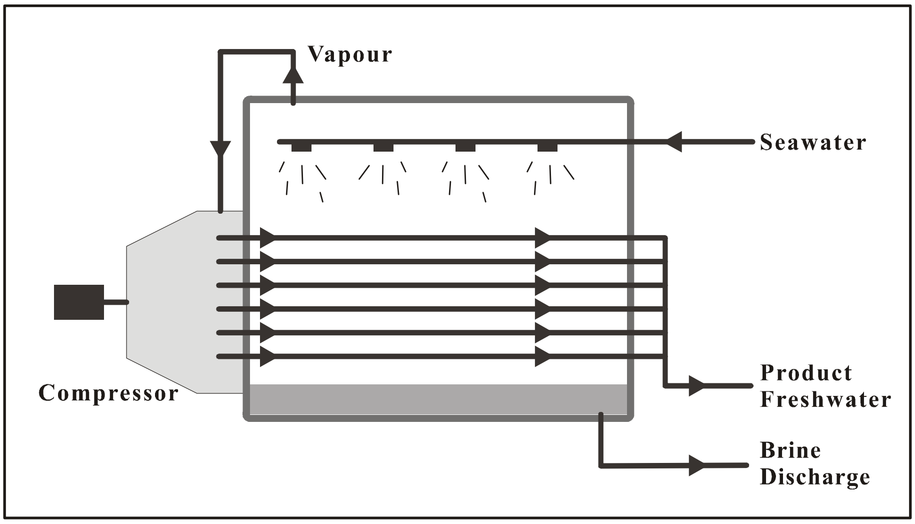


Figure 4 - Simplified MVC system

"The MVC process is attractive and competitive for production capacities less than 5000 m^3/d" [9]. Growth and expansion of process remained limited due to non-availability of large size vapour compressors.

7. ADVANTAGE AND DISADVANTAGE OF EACH METHOD

Choosing the most compatible method for the desired co-generation plant is of great importance to reach optimal performance and reduced economical investment. In Table 1, some characteristics of each process are shown.

Table 1 – Comparison of processes [1, 4, 5]

	MSF	MED	RO	MVC
Product quality (ppm)	5 - 25	5 - 25	250 - 500	5 – 25
Top brine temperature (^{o}C)	85 - 130	55 - 130	Ambient	< 70
Thermal energy consumption (kWh/m³)	55 - 120	30 - 120	-	-
Electrical energy consumption (kWh/m³)	3.5	1.5	4 - 7	8 – 14
Main form of energy needed	Thermal (heat)	Thermal (heat)	Mechanical (electricity)	Mechanical (electricity)
Manufacturing requirement	Medium	Low	High (for membranes)	Medium
Scaling potential	Medium	Low	High	Low
Commercially viable capacity	Large	Medium	Large	Low
Pretreatment	Medium	Low	Very high	Low
Tolerance to operational failure	High	High	Low	Medium
Tolerance to changing seawater composition	High	High	Very Low	High
Maintenance	Low	Low	High	Medium
Failure potential if corrosion occurs	Low	Low	High	Low

MSF process has a proven performance, having the world's largest installed desalting capacity, thus the availability of standard designs as also of equipment and qualified man power is greater than for other processes. The method is advantageous in large capacity ranges, its efficiency increases as the number of flash stages increases.

Gain output ration (GOR) is a ration of kg of freshwater produced per kg of steam consumed, it is used to measure the efficiency of the distillation plant. In MSF the "GOR is limited to around 12, because of loss in vapour temperature due boiling point elevation, pressure drop through demisters, condenser tube bundle and non-equilibration losses" [4]. Calcium sulphate scale formation is something to be avoided, it can only be removed with mechanical methods or expensive chemical pretreatment, the top bribe temperature and concentration is limited, owing this scale formation.

"MED plants are very flexible, the short start-up period, for heating up, grants an up to 95% annual availability. LT-MED has the operating temperature below the saturation limits of problematic scalants found in seawater. Scale is reduced to an insignificant level, enabling plants to operate for long periods (5 years in some cases) between chemical cleanings. The pre-treatment is simpler than that required for other processes. Rough seawater filters with screens of 3 mm open pores are sufficient for a safe and long term operation. Equally important is the fact that a low cost and harmless polyelectrolyte additive is used for feed pre-treatment, rather than sulfuric acid dosing which is often required with high temperature plants." [7]

"The GOR for MED is theoretically equal to the number of effects, but practically somewhat less, because of heat losses, the number of effects normally varies from 2 to 24" [4]. Higher efficiency could also be obtained by increasing the heat transfer area or the top brine temperature, as higher temperatures have increased risk of corrosion and scaling, also more expensive pre-treatment and construction materials are needed, it is all a matter of optimization to archive the lower water cost.

Mechanical vapour compression is a simple and reliable process, the disadvantage of it, is the limited capacity to about 5000 m^3/d of desalted water production, the non-availability of large size vapour compressors is the limiting factor.

Energy consumption of RO is the lowest if compared to other desalination processes. Pre-heating the RO feed water is a good option to reduce even more the costs, as long as the temperature limit of the membrane is not exceeded. Differently from the distillation processes, where cost of the product fresh water is almost independent of feed water salinity, in membrane processes the cost is directly affected by the salinity, therefore the cost for desalting brackish is lower than for seawater.

"RO membranes are in general very sensitive to fouling by organic molecules and by solid particles in suspension. It is of crucial importance to eliminate these molecules before feeding the RO system in order to maintain the desired performances and to avoid irreversible damages to the membranes. In fact, the determining factor for the success of a RO system is the efficiency of its pre-treatment." [1]

8. COST COMPARISON OF THE METHODS AND ECONOMIC CONSIDERATIONS

Many factors have influence over the final cost of the desalted water and thus affect the successful implementation of the chosen method. The plant capacity is an important factor to be considered, some desalination processes are most suitable for large capacity and others for lower. There is a significant economy of scale as plant capacity increases, reducing the desalted water cost. This effect has more influence over lower sized plants, at higher capacity only a few percents of the cost are reduced.

"Small nuclear reactors dedicated to produce heat, have higher water production cost than dual-purpose reactors. For example, a heat reactor coupled with MED has 30-40% higher water cost than a dual-purpose reactor" [10].

Another factor is the feed-water quality, lower salinity requires less pre-treatment, energy consumption is lower and the conversion rate higher.

"There is a method of material extraction, still in preliminary stages of development but showing significant progress" [1]. Seawater usually contains around sixty elements from the Periodic Table. Some of these elements are extracted from the concentrated reject brine of the desalination unit, not all the materials are worth extracting, but some of them are very expensive. Extracting these materials would singly enhance economic competitiveness, creating a third product for the co-generation plant.

Analysis with DEEP have shown that desalination cost ranges from 0.5 $\$/m^3$ to about 1.18 $\$/m^3$ depending upon the water plant type and size, energy source, specific and economic scenarios. RO based systems desalination costs vary from 0.5 $\$/m^3$ to 0.94 $\$/m^3$, MED vary from 0.6 $\$/m^3$ to 0.96 $\$/m^3$, and MSF around 1.18 $\$/m^3$ [1]. It should be remembered that water quality for RO process is about 250-500 ppm TDS, MED and MSF have a superior quality around 5 – 25 ppm TDS.

"The total integrated plant availability has a pronounced effect on the water costs. For example, by increasing it from 52% to 84% (variation of 32%), the water cost reduces from 1.33 to 0.91 $/m3 (about to 32%)" [1].

"Over a wide range of power sources and regional conditions, the difference between the water production costs by RO and MED tend to be small as compared to the large differences introduced by changes in discount rate. Independent of the energy sources and regions considered, in all investigated cases water production costs from MSF appear to be systematically higher than those from RO or MED" [10].

9. ADVANTAGE OF A DUAL PURPOSE PLANT (ELECTRICITY & DESALINATED WATER)

A dual purpose plant or co-generation plant consists of a nuclear reactor and a desalination system coupled to the reactor, sharing common systems and facilities, producing both, fresh water and electricity.

Co-generation plants have a number of economic advantages over single purpose plants. Due to sharing of facilities and equipment, the financial investment is lower. Some components are larger, having higher efficiencies, thus reducing the total fuel consumption. Also, the number of staff and energy used in a dual purpose plant is lower than in two single purpose plants, one producing electricity and other producing desalted water, because of the joint operation of shared facilities.

Coupling of distillation process like MSF and MED are mainly thermal, although some electricity is required for the pumps and other ancillary equipment. RO and MVC processes can be coupled using a standalone method, where the desalination unit is only electrically coupled to the power plant. Or, a contiguous method assuming the plants share a common seawater intake and outfall and may use the condenser cooling system of the power plant to preheat the feed water for the desalination process.

To determine the coupling scheme, the choice of desalination process is a major factor to be considered. There are two types of co-generation schemes: serie and parallel.

"In the serie co-generation, first the electricity is produced by expanding the steam in the turbine with an elevated backpressure, and then the extracted low grade steam passes to the brine heater to be used in the desalination process. This option requires relatively low investment and has an inherently higher efficiency" [1]. "It has reduced total energy consumption as compared to parallel method. Backpressure scheme is normally used for plants requiring higher power to water ration" [4]. A disadvantage of this method, is that once the backpressure is set, the power to water ration cannot vary.

In parallel co-generation, the steam from the reactor is divided, a part goes to the turbine to produce electricity and the other part is used in the desalination process. "This scheme has a higher flexibility than the serie method, but a lower efficiency, as the energy consumed would be the same as if the steam for desalination and electricity had been produced separately" [6].

A dual purpose plant requires a careful consideration on how the coupling would be made. Economical and operational aspect should be optimized. Also, safety aspect must be considered, to prevent the radioactivity from reaching the desalination unit, and the salt from reaching the reactor, normally two mechanical barriers and pressure reversal between the reactor primary coolant and brine are used. And to avoid any hypothetical contamination, the desalted water must always be monitored.

10. SUMMARY OF THE IAEA ACTIVITIES IN NUCLEAR WATER DESALINATION

"IAEA has been providing guidebooks, technical documents, and computer programs on nuclear desalination as well as technical assistance through the framework of technical co-operation programs, biennial workshop/training courses are arranged for the benefit of young scientists and engineers interested in relevant research in nuclear desalination" [3].

In 1998, a Coordinated Research Project (CRP) on Optimization of the Coupling of Nuclear Reactors and Desalination Systems was initiated, institutes from nine

Member States participated. "The CRP has accumulated relevant information on the latest research and development in the field of nuclear desalination and shared it with interested Member States. The CRP has produced optimum coupling configurations of nuclear and desalination systems, evaluated their performance and identified technical features, which may require further assessment for detailed specifications of large-scale nuclear desalination plants" [6]. It was completed in 2003, and published in 2005 as IAEA-TECDOC-1444.

A second CRP on Economics of Nuclear Desalination: New Developments and Site Specific Studies was carried out by ten Member States. "The objective was to find more precise and validated methods for desalination cost evaluation and discuss new developments adopted, aiming to further reduce desalted water costs" [1]. It started in 2002 and was completed in 2005. In 2007, it was published as IAEA-TECDOC-1561.

In 2007, a status report was published under the name of Status of Nuclear Desalination in IAEA Member States (IAEA-TECDOC-1524). "The report covers salient aspects of the new generation reactors and a few innovative reactors being considered for desalination and other non-electrical applications, the recent advances in the commonly employed desalination processes and their coupling to nuclear reactors" [3].

A software, based on spreadsheet routine, for economic modeling and analysis of various desalination and energy source options, was released in 1998 under the name of Desalination Economic Evaluation Program (DEEP). Since its release the program is under continuous development, incorporating new ideas and features. In 2006, DEEP-3.1 was released.

11. CONCLUSIONS

The small innovative nuclear reactor FBNR is an adequate reactor to be used as a double purpose plant to produce electricity and desalinated water simultaneously. The inherent safety and passive cooling characteristics of the reactor permit its construction in or near urban area.

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