NUCLEAR DESALINATION DEMONSTRATION PLANT (NDDP) AT KANUPP*

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ABSTRACT

The lack of adequate supplies of safe drinking water is one of the most pressing problems facing the world today and Pakistan is not the exception. Constant and abundant power and water supply is a guarantee for the economic development of a country. Especially, water shortage in the coastal areas of Pakistan including Karachi have become more acute than ever and the problem has become persistent. Therefore clean and fresh water availability is a major factor for the development of the coastal belt of the country. Pakistan has sizeable sea coast extending from Karachi to Iranian border, this belt extends up to 1046 km of this 930 km is from Karachi to Gawader. The annual rainfall in this belt is very low. Karachi, the major port city of the country is the most densely populated with population crossing the 20 million mark.

The prospects of using nuclear energy for dual purpose to generate electricity and potable water production on large-scale have become attractive since it is technically feasible, economical and safe alternative to fossil energy options.

First ever Reverse Osmosis (RO) based sea water desalination plant of 100,000 gallon/day was built, installed and commissioned in Karachi by indigenous efforts of Pakistan Atomic Energy Commission (PAEC) engineers which is in operation since 2001 at Karachi Nuclear Power Plant (KANUPP).

Nuclear Desalination Demonstration Plant (NDDP) having a total installed capacity of producing fresh water up to 4800 m^3 / day (1MGPD) has been coupled with KANUPP through an Intermediate Coupling Loop (ICL Loop). KANUPP is a CANDU type, 137MWe, Heavy Water Reactor. NDDP is producing high quality water suitable for industrial and drinking purpose use re-mineralized with food grade chemicals. Interest in using nuclear energy for producing potable water has been growing worldwide in the past decade. The purpose of this project was to demonstrate that production of potable water using heat source of a nuclear reactor is technically and economically a viable option.

The public acceptance of this technology and the experience gained from this project in the field of design, construction, commissioning and operation will be utilized to establish large scale thermal seawater desalination plants in future along the coastal belt where there is an acute shortage of power and fresh water due to non-availability of any natural resources.

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*(MED Thermal Desalination Plant of Capacity Up To 4800 M^3 / Day) CO-PRODUCTION OF WATER AND ENERGY – A DUAL PURPOSE NUCLEAR POWER PLANT

1. Principal Engineer, PAEC

1.0 INTRODUCTION

In the wake of the looming water crisis it is becoming increasingly clear that all available and appropriate technologies including nuclear have to be used for the sustainable development and management of fresh water resources in Pakistan. The future requires effective integration of energy resources to produce power and desalinated water economically with proper consideration for the environment.

To produce fresh and clean water utilizing the heat source from nuclear reactor, we need to have nuclear power plants. Presently there are three nuclear power plants operating in Pakistan. Amongst them one is KANUPP of 100 MWe located near the Arabian Sea and the other two in Chashma, namely, CHASNUPP 1 & 2 of 325 MWe each. Apart from these, Nuclear power plants under construction phase are CHASNUPP-3 & 4 of 340 MWe each (to be connected to national grid in 2016) and Karachi Coastal Power Projects K2 & K3 of 1100 MWe each (expected to be connected with national grid in 2020/21).

In 2009, in first phase of its program for producing potable and quality industrial water using nuclear energy, KANUPP has successfully demonstrated, through an Intermediate Coupling Loop, the utilization of nuclear heat generated in the reactor core, to produce 1600 m^3/day (0.4 million gallon/day) of distilled water of quality less than 20 ppm for industrial use whereas for drinking purpose it is less than 300 ppm after re-mineralized with food grade chemicals. A thermal seawater desalination plant of Multi Effect Distillation, MED type, an emerging and efficient technology, has been selected for this purpose. A total of 4800 m^3/day has been planned to produce using the same facility considering the future demand for on-going nuclear projects in Karachi coastal areas.

To keep themselves acquainted with latest technologies and updates PAEC is in continuous touch with international community. International Atomic Energy Commission (IAEA) has been providing assistance for safety evaluation of the project during the design stage through expert mission, and has also provided manpower training under a Technical Cooperation Program.

For the purpose of economic evaluation and analysis of various desalination and energy source options, IAEA has also developed a Desalination Economic Evaluation Program (DEEP). This is to enable the distribution of costs to the two products in a co-generation plant (i.e. power and water). DEEP uses the “power credit method”, i.e. the loss of electricity generation is charged to the water costs. This will help to develop our capabilities in economic evaluation of large-scale dual purpose nuclear power plants.

2.0 AIMS AND OBJECTIVES ACHIEVED

The main objective of the project is to demonstrate the technical and economic viability of coupling a nuclear power plant with a thermal desalination plant to produce high quality potable water. The experience thus gained has provided PAEC with in-depth understanding of the thermal desalination process and has gone a long way in preparation of the detailed feasibility report which shall be used to set-up large-scale desalination plants along the coastal areas of Pakistan.

PAEC has already been engaged in various activities regarding construction of nuclear power plants for energy with the provision of water production approach by short-term and long-term strategies. Hence it was felt necessary to acquire sea water desalination technology to be used for nuclear desalination as well as conventional desalination.

The great benefit was also achieved in a way that the agreement with the vendor was made such that PAEC got hold of technology as well for thermal and conventional desalination which has enabled us to build such resources self-reliantly in future.

In fact NDDP is amongst one of the many success stories that PAEC engineers have achieved through their indigenous efforts. The task of manufacturing, installation and commissioning assigned to engineers by the management of PAEC was successfully completed and it was practically demonstrated that PAEC engineers are capable of utilizing their experiences not only in power sector but can also contribute significantly in developing non-electric application of nuclear energy for the benefits of their countrymen.

3.0 DESALINATION PROCESSES

The long term solution for resolving the ever growing shortage of fresh water along the coastal areas is sea water desalination. Desalination has decisively proven during last 30 years its reliability to deliver large quantities of fresh water from the sea. Unlike oil, fresh water has no viable substitute. The sea is the unlimited source to create new fresh water through desalination.

Commercial seawater desalination processes that are proven and reliable for large scale freshwater production are multi-stage flash (MSF) and multi-effect distillation (MED) for evaporative desalination and reverse osmosis (RO) for membralie desalination. Vapour compression (VC) plants based on thermal and mechanical vapour compression are also employed for small and medium capacity ranges. These processes have their inherent advantages and disadvantages.

4.0 NUCLEAR DESALINATION (WATER-ENERGY NEXUS)

What is it ?

- Any co-located desalination plant that is powered with source of nuclear energy (electrical and/or thermal)

Why?

Viable option to meet:

- Increasing global demand for water & energy
- Concerns about climate change
- Volatile fossil fuel prices
- Security of energy supply

Nuclear desalination is defined to be the production of potable water from seawater in a facility where a nuclear reactor is used as the source of energy (electrical and/or thermal) for the desalination process. Only a portion of the total energy output of the reactor is used for water production. 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 seawater intake and outfall structures.

Nuclear energy is already being used for desalination, and has the potential for much greater use. The use of well-established and advanced nuclear energy technology for seawater desalination is recognized as providing dual benefits namely the promotion of nuclear energy utilization and security of freshwater resources. The use of nuclear energy to produce potable water by seawater desalination has been considered as far back as in the 1960s.

5.0 HIGHEST DEGREE OF SAFETY IS INEVITABLE IN A NUCLEAR DESALINATION PLANT

The main objective of safety in a Nuclear Desalination Plant is to protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defense against radiological and other conventional hazards. The safety of a nuclear desalination plant depends mainly on the safety of the nuclear reactor and the interface between the nuclear plant and the desalination system. At least two mechanical barriers must be incorporated. Direct supply of steam from the reactor core to the desalination plant is not suitable for desalination without an intermediate barrier. There should be suitable provision for monitoring the radioactivity level in the isolation loop and desalination system. In case of a Pressurized Heavy Water Reactor (PHWR), the tritium level in the heating steam and product water must be checked regularly. Adequate safety measures must be introduced to ensure no detectable radioactivity release to the product water. Any adverse effect of discharging effluent from desalination plant should also be monitored. The feasibility of integrated nuclear desalination plants has been proven with over 150 reactor-years of experience.

6.0 NUCLEAR DESALINATION DEMONSTRATION PLANT (NDDP) AND REVERSE OSMOSIS (RO) PLANT AT KANUPP (AN INDIGENOUS EFFORT OF PAEC ENGINEERS)

Installation of NDDP and RO plants utilizing our own resources is amongst one of the many achievements accomplished by PAEC engineers. Both the plants under discussion were manufactured, installed and commissioned indigenously under the supervision of skillful manpower. It has been an example of the best utilization of experiences and skills of their workers. Engineers of KANUPP are operating and maintaining these plants efficiently since many years. Through their sincere efforts and hard work PAEC has proved that self-reliance can always be accomplished provided an appropriate environment given and confidence is shown on their own abilities.

The NDDP, producing fresh and pure water, commissioned in 2009 has been operating successfully since then. It is based on Multi Effect Distillation (MED) process which has a fairly long history. It is the oldest large scale evaporative process used for producing significant amount of desalted water from seawater. Thermal energy to NDDP is provided through a closed loop re-circulation system in which thermal energy of the extraction steam from turbine is provided to the heat exchanger (re-boiler) for the production of secondary steam.

Currently the plant is producing 1600 m^3 / day of water with only one MED battery having eight effects. However the total installed capacity of the plant is 4800 m^3 / day (one million gallon per day) with second MED battery expected to be in place in future as per requirement.

In developing countries like Pakistan the emphasis on getting the best technology which inherent simplicity and reliability is really a blessing. Simple and rugged design was preferred so that technical skill required for maintenance and operation can match to that available at site.

6.1 INCORPORATION OF A COMPREHENSIVE SCHEME FOR THE ISOLATION

As an international practice, it is necessary to incorporate an isolation loop. This avoids the possible risk of contamination under normal operating or due to radiation under certain accidental conditions. The steam from the thermal cycle of KANUPP turbine may contain radioactive materials in very little amounts and it can pose a constant safety threat and may contaminate the whole desalination product. Hence in a nuclear desalination plant it is necessary to prevent transport of radioactivity into the product water since the supply of fresh water to the population or plant facilities should always be contamination free. This has been effectively accomplished by suitable design features which included multiple barriers and pressure differentials to block transport of any radioactive materials to the desalination plant, and with appropriate monitoring before distribution of the product water.

At KANUPP’s NDDP plant multiple barriers are in place to ensure protection against such radioactivity leakage into the NDDP loop. Safety feature is provided through an isolation scheme called Intermediate Coupling Loop which consists of a heat exchanger, a re-boiler and associated valves and piping.

Further, an extra safety barrier in isolation is achieved by selecting MED type technology in which design it is inherent that product water of its 1st effect is not cascaded with the final product, instead it is re-circulated for the make up of NDDP re-boiler. This eliminates even the smallest chance, if any, of mixing any radioactive contamination to final product water.

The working principal of isolation scheme is based on Low pressure-High pressure-Low pressure (LHL) strategy. In LHL system, isolation loop kept at high pressure as compared to primary regenerative heater and main feed water loop of NDDP. This provides the safeguard against the entry of any radioactivity from low pressure primary loop to high pressure isolation loop.

Raw water is supplied by means of a separate scheme through sea water pump of 1300 m^3 / h capacity installed in the pump house of KANUPP, which supply the clean seawater to the NDDP. A simplified schematic diagram of NDDP plant is shown in fig #1.

6.2 PRINCIPAL OF MULTIPLE-EFFECT DISTILLATION (MED)

The principle of Multi Effect Distillation consists in the utilisation of the latent heat released by condensation of the vapour produced in each effect for the evaporation of seawater in the following effect. Vapour multiplied by placing several evaporators (effects) in series under successively lower pressures. The main advantages of MED technology derive from the low operating temperature (65 °C), which significantly reduces scale formation phenomena and contributes to prevent major corrosion risks.

6.3 SALIENT FEATURES OF NDDP PLANT AT KANUPP

Salient feature of NDDP is shown in table # 1.

Table # 1

Commissioned	2009
Net Production	66.7 ton / hour (0.4 Million Gallon / Day)
Total Dissolved Solid(product water)	Less than 20 ppm
Total Dissolved Solid(potable water)	Less than 300 ppm (re-mineralized)
Net Output Ratio	6.2: 1
Bleed Steam From Turbine	34 ton / hour
Steam Produced at NDDP Re-boiler	26.7 ton / hour
Steam Consumption at MED	10.7 ton / hour
Steam Temperature	75 °C
Pressure at Re-boiler	0.385 bar(a)

6.4 NDDP IS AN IMPORTANT STRATEGIC ASSET OF KANUPP

In the early few years of KANUPP history in seventies there was plenty of water available for KANUPP through the Karachi Water & Sewerage Board (KWSB). But as the population of the metropolitan city grew, the shortage of water became acute throughout the city and so in the vicinity of coastal areas which include KANUPP also. According to KWSB source, for Karachi, it is estimated that a deficit of about 100 million gallons per day (MGD) exists. As for any power plant, water is life line. The only option left with at that time was water tankers which have already become an everyday demand by millions in Karachi, but even this wasn't a reliable source due to the long distance tanker has to travel and security problem in the city.

As the uninterrupted supply of water, for a nuclear power, is of utmost importance because it is not only needed for smooth and continuous running of the plant but the safety requirement of nuclear power plant depends a lot on the availability of clean water. In a nuclear plant there is an additional requirement of water. When a fossil fuel plant is shut down, the source of heat is removed. When a nuclear plant is shut down some heat continues to be generated from radio active decay, though the fission has ceased. This needs to be removed reliably, and the plant is designed to enable and assure this, both with routine cooling and also Emergency Core Cooling Systems (ECCS) provided in case of major problem with primary cooling.

Hence it was felt that there was a definite need to set up a cheap and reliable source which not only fulfill KANUPP requirement uninterrupted but also serve to supply water in the surrounding coastal areas for public benefits.

So what was the solution?

Pakistan Atomic Energy Commission started to explore the possibility on Desalination of Seawater. Soon the Engineers of PAEC found the way through their efforts. Keeping in view the unlimited source of raw seawater near by two desalination plants both using different types of technology i.e., Reverse Osmosis (RO) and Multi Effect Distillation (MED) were installed and became functional.

6.5 SALIENT FEATURES OF RO AT KANUPP

Salient features of two trains of Reverse Osmosis Plant operational at KANUUP summarized in table # 2.

Table # 2

Operational	2001
Type	Seawater Reverse Osmosis
Capacity:	2x50,000 IGPD (454 m^3 / d)
Design Permeate Flow	9.5 m^3 / h per train
Design Raw Water Inlet:	21 m^3 / h per train
Design Recovery	45 %
No. of Pressure Vessels	Three (03) per train
No. of: Membranes:	Five (05) per vessel
Feed Water Source	Deep Water Wells

6.6 FUTURE WATER DEMAND BY KCPP (K2 & K3)

Spadework for construction of two 1000MWe nuclear power plant has already been started. The installation of these two large-sized Nuclear Power Plants along Karachi coast by PAEC will fulfill the growing needs of power and water in the Karachi metropolitan region. The Projects, known as, Karachi Coastal Power Projects, (KCPP, K2 & K3) will require a huge amount of uninterrupted water supply for their construction and smooth operation. It is estimated that there will be daily demand of one million gallon for this new project. It is expected that these plants will start generating electricity within next 6 to 7 years. It is hoped that NDDP will provide cheap source of high quality water to these plants and will play vital role in timely completion of the national projects.

7.0 SOME OF THE COUNTRIES USING NUCLEAR ENERGY FOR PRODUCTION OF WATER

PAKISTAN: KANUPP, NDDP (4800 m3/day), incur a 2 MWe loss in power from the plant.

JAPAN: 14,000 m^3/day of potable water, and over 100 reactor-years of experience accrued.

KUWAIT: Considering cogeneration schemes up to a 1000 MWe reactor coupled to a 140,000 m^3 / day desalination plant.

QATAR: Considering nuclear power and desalination for its needs which reached about 1.3 million m^3 / day in 2010.

INDIA: 1800 m^3 / day cascaded with 4500 m^3/day MSF. They incur a 4 MWe loss in power from the plant.

KAZAKHSTAN: MED & MSF type Decommissioned (1999) after 26 reactor years.

8.0 CONCLUSION

The milestone achieved in producing fresh, clean and drinking water using nuclear energy source has been doable through indigenous efforts of Pakistan Atomic Energy Commission engineers. PAEC has again taken the lead in another specific areas i.e., sea water desalination.

Benefiting the people of Pakistan in various fields has always been motive of PAEC engineers and scientist not only in the energy sector but it is also pursuing numerous programs in the field of Basic and Applied Sciences, Food, Agriculture and Biotechnology and Human Health.

In forthcoming era the visions of using nuclear energy for dual purpose and producing potable water on large-scale have become priority since it is the need of time, attractive, technically feasible, economical and safe alternative to fossil energy options. Nuclear desalination is generally very cost-competitive with using fossil fuels.

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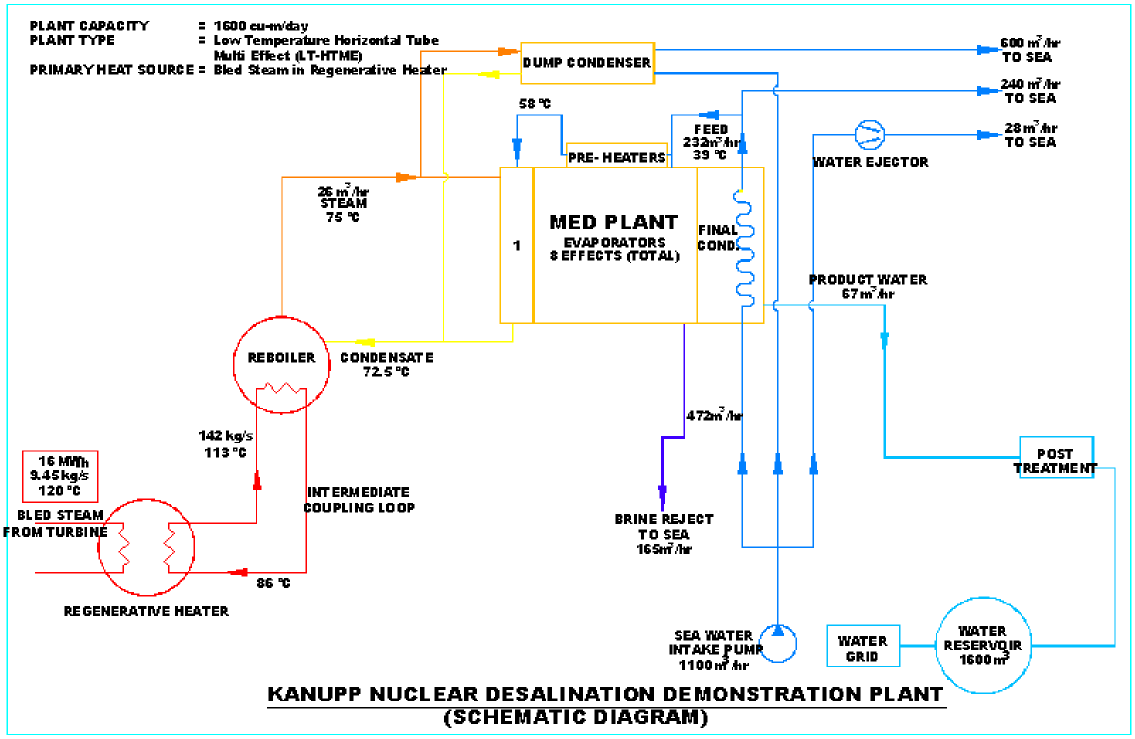
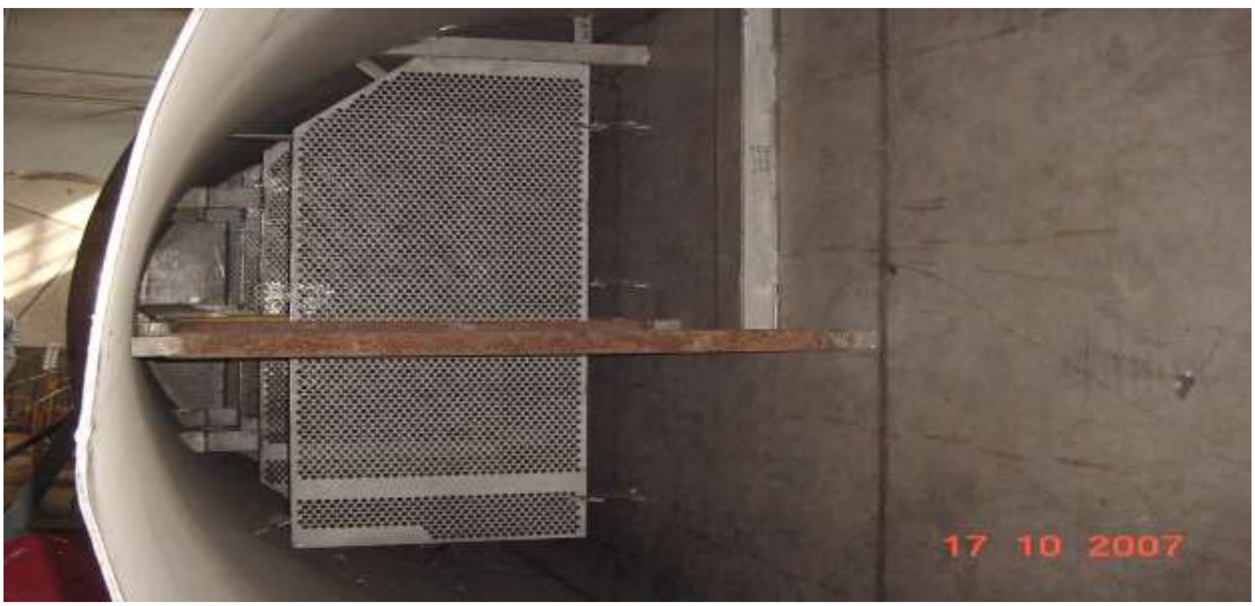
Fig # 1: A simplified schematic diagram of NDDP



A PICTORIAL VIEW OF VARIOUS MANUFACTURING STAGES OF NDDP EQUIPMENT

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NDDP EVAPORATORS

TUBE BUNDLES OF NDDP RE-BOILER

NDDP AT KANUPP