Development policy on new generation of nuclear power combined with desalination in China

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Abstract The potential market for desalination industry is forecasted in China for a long term. A co-generation policy is proposed in power production and desalination. It has been predicted that the desalination would become a huge industry in China provided that the technology of desalination is improved and fresh water cost reduced to a certain level accepted by Chinese residents.

Keywords Nuclear power program, Desalination, Nuclear power, Co-generation

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1 Introduction

The nuclear power plants put into operation during the period of construction peak face to be decommissioned therefore the energy supply gap will come in three or four decades. It is predicted that the new generation of nuclear power would appear more on the energy stage in 21st century as it features safety, economy and much easier to be accepted by the public in the worldwide.

At the same time there are problems in meeting the increasing demand for fresh water in the world. Thirty percent of the world's population will have faced water shortages by the year 2050, according to the United Nations Environment Program. With population growth and these locational, annual and seasonal imbalances, China also faces water shortages now and will face a shortage increase in the future. The water resources average only 2200 m^3 per capita, one fourth of the world's average. It will further reduce to 1750 m^3 in 50 years when the population in China peaks 1.65 billions (b for short below).

The water shortage should solve by comprehensive measures, especially increasing water resources and economizing on water uses. Seawater desalination project is a key measure to increase the water resources though the technology and its products may be too expensive for Chinese residents to accept.

In this paper, the new generation of nuclear power is discussed in co-generation of electricity and desalination. The potential market in desalination industry is forecasted in China for a long-term. A proposal on development of technological and economical modeling is presented here. As a result the desalination would become a key sector of public industries in two or three decades to fill the fresh water gap in some regions, northern China.

2 Background

2.1 Nuclear power in future

The nuclear power supplied 16% of global electricity with the current capacity of 350 GW (referring to electrical power, the same below). World nuclear power remains almost static in capacity. During an outlook period, the retirement of several units will offset the increase in nuclear output from construction of new plants. But in three to four decades, a great number of nuclear plants will be retired and a large gap of electricity supply will appear then.

A special report on Emission Scenarios by the Inter-governmental Panel on Climate Change provides a picture of future energy needs, including substantial increases in use of nuclear power with a median prediction of more than 1500 GW. At some time in future, the new generation of nuclear power will spread out rapidly to meet the electricity demands in the world.

The results of government-sponsored studies were documented in the October 2001 report titled "A Roadmap to Deploy New Nuclear Power Plants in the

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United States by 2010". Six designs including AP600/1000, the Westinghouse PWR design with passive safety features and the Pebble Bed Modular Reactor (PBMR), developed in the Republic of South Africa, were found to be possibly deployable by 2010. A document titled "A Technology Roadmap for Generation IV Nuclear Energy Systems" was issued by the U.S. DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum in December 2002. The objective for Generation IV systems is to have them available for wide-scale deployment before 2030. The missions for the six Generation IV systems are shown in Table 1.It is noticed that all six systems may consider bottoming cycles for desalination.

Table 1 The energy production technology options for each Generation IV system[1]

Generation IV system (T_{outlet})	Hydrogen production		Heat delivery		Advanced cycles for electricity production		
	I-S process	Ca-Br process	Process heat	Desalination	Supercritical CO_2 Brayton	Water Rankine Supercritical	Helium Brayton
GFR (850℃)	P	S	S	O			P
MSR (700~850℃)	P	S	S	O			P
SFR (550℃)				O	S		
LFR (550℃)		P	S	O	P	S	
(800℃)				O	S*	S*	
SCWR (550℃)				O		P	
VHTR (1000℃)	P		S	O			P

P: Primary option; S: Secondary option; O: Option for all systems.

*Bottoming cycle using heat at lower temperatures available after higher temperature heat has been used for hydrogen production.

China has exercised a development policy of nuclear power in appropriate scale. Some officials had previously announced plans for a nuclear power capacity of around 20 GW by the year 2010, 35~50 GW by 2020, 120 GW by 2050.[2,3] In a median-term, China will choose the new generation of nuclear power for its own plans.

In order to increase the utilizing efficiency of nuclear energy and provide low-pressure steam to desalting plants, co-generation of nuclear power and desalination, it's believed, is well on the way to turning this possibility into a reality.

2.2 Potential market of desalination in China

With a total balance mode, the Reference [4] has forecasted China water resources in five decades. The country demands for water divide into four categories: macrocosm's environmental uses, surroundings uses for producing and leaving activities, agricultural and forest uses, and urban and rural water uses. In general, the first uses consume 50~60% of surface water and renewable ground water, and rest (approximately 50% in China) covers last three uses.

It is assumed that the predicted population of China would peak 1.65 billions. Four large drought regions in northern China consist of fifteen provinces and cities with 43% of the total population. Average annual predictions of water shortages in these regions by the year 2050 would be 267.3 bm^3. At the same time there is a water resources surplus of approximately 340 bm^3 in southern China with abundant rainfall.

The country is planning a great "South Water to North" project. Considering some restrictive factors, only a portion of the surplus could be transported to North, saying about 200 bm^3, therefore a gap of 67.3 bm^3 would remain in 15 provincial regions.

The gap for residential use in Hebei, Shandong, Liaoning, Tianjin, and Beijing (equipped with transfer facilities) will probably be bridged by desalination.

Finally, according to a preliminary estimate, the prediction of desalination capacity in five Provinces and Cities mentioned above in 2050 will probably be 2.1 billion m^3/a, equivalent to 7 million m^3/d.

2.3 Mainstream technology of desalination[5,6]

The types of desalination technologies used in median- and large-size plants comprise Multistage Flash (MSF), Multi Effect Distillation (MED), which both share about 65% of the world's installed capacity, and Reverse Osmosis (RO) making up about its 30%. MSF has been the mainstream for large-size water production in the world but its position is now being challenged by the latest developments in MED. Analysts believe that this type of process offers significant potential for water cost reduction. In recent years, specific investment cost of a MED plant was 10~20% lower than MSF. Two recently constructed co-generation plants, Jebel Ali K and Layyah, with comparable local conditions and identical capacities are shown in Table 2.

RO technology by totally electrical driving could be used to balance difference between peak and valley loading by combination with aquifer storage and recovery.

Middle East is the biggest user of desalination with over 50% of the world's capacity. The technical and economic approaches in this region have created a new trend towards building dual-purpose plants in a large scale, and led consequent results of specific investment, water and electricity cost reductions. Table 2 has listed some projects showing above trends.

Table 2 Desalination units in Middle East

Name	Nation	Type of technology	Electricity and water size (MW/m^3 •d^{-1})	Capital cost (\$•m^{-3}•d^{-1})	Electricity and water cost (¢•(kWh)$^{-1}$/\$•m^{-3})	Status
Jebel Ali K	UAE	MSF/NGCC*	/ 2×19k	1100	2.3/0.7	Operation
Layyah	UAE	MED/NGCC	/ 2×19k	980		Operation
Taweelah-A1	UAE	MED/NGCC	/14×17k	Total 1.5b	2.3/0.7	Contract 2003
Taweelah-A2	UAE	NGCC	710/190k		2.3/0.7	Construction
Ruwais	UAE	MSF/NGCC	500/15k	Total 600M		Operation
Jubail	Saudi Arabia	NGCC	700/720k	Total 2b		Contract
Al-Khobar III	Saudi Arabia	MSF/NGCC	650/630k			Construction
Shoaiba II	Saudi Arabia	MSF				Construction
Jubail	Saudi Arabia	RO	/78k			Construction
Ashdod	Israel		/139k	Total 110M	/0.6~0.65	Biding
Barka	Oman	NGCC	427/76k	Total 415M		Contract
Al-Zour	Kuwait	RO	/109k			Contract

* NGCC: Natural gas combined cycle

Institute of Seawater Desalination and Multipurpose Utilization, State Oceanic Administration (Tianjin) is a mainstay in R&D of desalination. In recent years, several types have been developed such as low temperature multi effect distillation, low temperature vapor compression desalination and water treatment with RO. A recommended type is shown in Table 3.[7]

Table 3 Performances of low temperature MED

Size (m^3•d^{-1})	GOR*	Consumption of steam (t•h^{-1})	Consumption of electricity (kWh•m^{-3})	Steam pressure (MPa)	Inlet temperature (℃)
5000	10.0	20.5	1.5	0.225	71
10000	8.7	48.0	1.6	0.034/0.225	70
19000	10.0	79.2	1.2	0.033	70

*Gained output ratio: tons of distillate/tons of steam

3 Water cost estimate

Taking a sample of low temperature MED with 50,000 m^3/d unit capacity, plant investment cost may be US$30 m plus seawater engineering cost 6 m. The water cost is calculated by a formula as following:

$$\text{Water cost} = 0.1 \times \text{steam cost} + 1.5 \times \text{electricity tariff} + \text{financing cost} + \text{operating cost},$$

where let us assume that the MED has a GOR = 10; electricity consumption is 1.5 kWh/m^3; all investment is debt with 6% of annual rates and 20 years of maturity for local and foreign currencies; foreign exchange rate is 1 US$ = 8.3 RMB yuan, then

$$\begin{aligned}\text{Water cost} &= 0.1\times 18\ \text{yuan/t} + 1.5\times 0.2\ \text{yuan/(kWh)} + (3 + 3\times 10\times 6\%)\times 10^8/(5\times 10^4\times 3\times 10^2\times 20)+1.0\\ &= 1.8 + 0.3 + 1.6+1.0 = 4.7\ \text{yuan/m}^3\end{aligned}$$

This is a preliminary estimate to show the suggested direction of R&D on economic and technical features below.

4 Development strategies

The water cost of above estimate is now unacceptable for urban and rural residents in China. In order to industrialize the technology in China, it's evident that scientists and engineers have been challenged to the economic acceptability based on optimizing technical performances and financing mode.

4.1 Key points of R & D

Seeing that above analysis on water cost, the steam cost consumed on unit water production is 38% of the total cost, therefore one of key R & D points is to reduce energy consumption, especially steam.

4.2 Energy solution－new generation of nuclear power

In order to cut down the water cost, other point is to utilize lower pressure steam from the turbine cold end. In fact, overall efficiency of co-generation has achieved exceeding 70% equivalent to a 15~35% reduction in primary energy usage. This allows the desalination plant to make economic savings where there is a suitable balance between the heat and power loads.

Considering the new generation of nuclear power in China in coming one or two decades, it would be proposed to design new power plants for co-generation. Let us analyze the concept design with data of PBMR developed by South Africa and China conditions as an example. Steam consumption is assumed 30 kWh/m^3 and the leveled tariff is 3.0¢/(kWh). Then the water costs about \$0.6/m^3. If 70% of the reactor output is used to generate electricity and rest 30% to produce water, so the capacity of a PBMR unit becomes 77 MW and 40,000 m^3/d. Co-generation is also feasible for AP600/1000 with 3.24¢/(kWh) of electricity tariff. The water cost comes to \$0.52/m^3.

Above results show that the new generation nuclear power plants combined with a group of MSF or MED units will certainly have a great future. Specialists have suggested that new types of coal-fired power plants and refuse incinerators could serve as energy resources of the co-generation in China.

4.3 Financing consideration

Financing cost is 34% of the total water cost according to above estimate. The successful introduction of Independent Water and Power Producers (IPPs and IWPPs) with project financing has created a new trend towards spread of water industries in Middle East. However the project financing has not only advantages but also disadvantages referring to its experiences of coal-fired power plants in China. In fact, financing instruments for funding projects are varied. Some of them serve fund cheaper than project financing provided that the borrower has a good credit rating.

Opposite of IWPP, one company could be arranged to invest a group of co-generation plants and exercise average water and electricity price in whole lifetime by means of averaging old plants' without loan payback and new ones' with higher cost of pay off the loan. A water producer could invest power plants to share their low- pressure steam with much lower cost.

5 Conclusions

(1) The potential market of desalination industry is 2.1 bm^3/a equivalent to 7 mm^3/d for the residential use there in coastal regions, northern China.

(2) With a top priority, some brackish water resource in the arid North-West China should be investigated and developed. The water cost may be acceptable there for cost of brackish water desalting is 1/3~1/5 of seawater's.

(3) The international trends in co-generation and increasing plant scale with advanced technologies should be followed. The new generation of nuclear power as well as new type of coal-fired power plants planned in northern China should consider as co-generation to provide cheap low-pressure steam for desalination.

(4) The current economic and technical approaches of desalination couldn't meet the heavy task because of the water cost unaccepted in China. Chinese scientists and engineers have been challenged to improve its economic and technical features so that the water cost further reduces to a certain level accepted by Chinese residents and it will become a huge sector of public industries in five decades.

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