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China Desalination Cost Compared to Global Long-Term Estimation

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Abstract: The future overall trends of desalination cost are estimated using least-square fitting method based on Excel, and four major impact factors, named technology, feed water, energy sources and capacity, are discussed and prospected. Five different types of desalination technology are presented and bench-marked for long-term use. RO and MSF are dominant technologies. Six different input water sources are used. There is no significant change in the sources distribution during the past 20 years. Wastewater should be more important. Three different energy supplies are reviewed: conventional fossil based energy, nuclear energy and renewable energy sources. Large capacity has obvious cost advantage over the small one for the same technology. At present, the cost of desalination using a conventional source of energy is lowest. In this paper, statistical analysis points indicates a total production cost of less than US 0.5 $/m^3$ in 2020. This will probably continue to drop due to effects of scale and reach US 0.35 $/m^3$ after year 2020. Wastewater is less costly to desalinate, approximately US 0.3 $/m^3$ from the year 2015. Brackish water will reach US 0.2 $/m^3$ at year 2015. China water and desalination projects were discussed compared to the global production and cost estimation from different points. In china, the open discussion is preferred as the result of this study in order to reduce the price and impact of desalination.

Keywords: desalination; cost estimation, technology; feed water, energy; capacity

1. Introduction

Desalination is an important method for producing potable water and is a rapidly growing technology worldwide. Historically, desalination has been a freshwater supply opportunity for a long time, especially at remote locations and on naval ships off shore. With the rapid growth of water desalination technology in recent decades, the development has continued in many arid, semi-arid areas. The capacity of desalination increased rapidly worldwide, from 8000 m^3/d in 1970 to about 32.4 million m^3/d installed or contracted, over 15,000 industrial-scale desalination unites by 2001, seawater desalination plants of 19.1 million m^3/d and non-seawater of 13.3 million m^3/d [1,2].

The contracted desalination Plants capacity has also grown to 80.47 Mm3/d, which represents the output of over 15,600 desalination facilities worldwide while the online capacity almost 75 Mm3/d [3]. The total capacity contracted has now reached to 86 Mm3/d and the online amount of 80 Mm3/d, a rise of about 6 million for both since the 2012-2013 year book [3]. The data presented here is almost at the end of year 2013.

A variety of desalting technologies has been developed over the years, primarily thermal and membrane processes. The cost of desalination, either thermal or membrane, is inversely proportional to the production capacity. The market is also driven by the falling costs of desalination, which are due to the technological advances in the desalination process [4]. The desalination plant size is important when it comes to capital and production cost. Today's desalination plants and methods require large amounts of energy which is costly both in environment impact and money.

The cost estimation is one issue surrounding the desalination industry that should be carried out in an efficient and reliable manner, as costs is a crucial factor in government decision making and planning. Furthermore, how to reduce the cost from different impact factors is the driving force to research on desalination, as well as being paid close attention by industry. Desalination cost estimation is varying from site to site and country to country for the cost ranges per cubic metre [5].

This variability exists because it depends upon many factors, such as the desalination technology, feed water salinity, energy type and availability, plant capacity and plant location. Previous models to calculate cost estimations have the disadvantages that they are complicated and require a vast amount of parameters which are not easily to be collected. In addition, most of the models only focus on single scenario, such as

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seawater desalination by RO, or desalination using certain energy.

This paper estimates and analyzes the cost trends considering multi factors and the simple method named fitted least-square based on Excel is used to estimate the overall cost trends. The variety factors are analyzed for reducing the cost and the experience in China is discussed. The paper shows that both the correlation coefficients (R^2) and the actual cost data display that the fitted least-square based on Excel is suitable for forecasting the overall desalination cost trends.

1.1. Method and Data Collection

In this paper, the method is collection of data and application of the least-square fitting based on Excel to estimate overall trends of desalination cost and discuss four major parameters named technology, feed water, energy sources, and capability, as well as how the factors influence the cost trends. Least-square fitting, including linear and nonlinear, is a mathematical optimization techniques. It is a procedure for finding the best-fitting curve by minimizing the sum of the squares of the offsets ("the residuals") of the points from the curve [6]. It can be applied for getting unknown data simply, which makes the results have the minimum offsets between the obtained and actual data. The linear fitting, which is the simplest and most commonly applied form of linear regression [5] was used for estimating the overall cost trends in this paper. According to historic cost data collected from previous work, we can get the fitting equation to estimate the future cost. In the paper by Cheng and Ren (2010) [7], the method is used for cost estimating in transmission line construction. The result shows that it is feasibility with certain accuracy for using least-square fitting for cost estimation.

2. Data Collection and Analysis

There are three types of desalination methods used throughout the world for a wide range of purposes, but mainly for potable water production for domestic and municipal use.

a. Membrane Systems: Reverse osmosis (RO) or Electro dialysis and Electro dialysis Reversal (ED)
b. Thermal Processes (TP): Multi-Stage Flash Distillation (MSF) Multiple-Effect Distillation (MED), and Vapor Compression (VC).
c. Other Desalination Processes: Different types of water can be desalinated through many other processes including small-scale ion-exchange resins, freezing, and membrane distillation (MD) [8]. The MSF and RO processes dominate the market for both seawater and brackish water desalination, sharing about 88% of the total installed capacity [1].

The distribution in the last 20 years is presented in Figure 1, and it shows that installed capacity of RO processes increased significantly, while MSF declined steadily, since it cost more energy. Before 2001, there is no or little installed capacity of hybrid, but it increased to 2% in 2013-14. Nowadays, the RO alone is the main deriving for desalination technology, which mainly because RO has advantages over other technologies. After nearly 40 years development, RO desalination technology is already quite mature. Salt reduction with RO is higher than 99.3%, with the permeable flux, the range of available operating pressure, anti-pollution and anti-oxidation capacity continually increasing. In addition, RO also has smaller investment, less energy consumption, lower cost, and short construction period. After the treatment of RO, water can achieve the WHO standards for drinking water. This makes RO to be the most competitive method of seawater and brackish water desalination [9].

Ninety –seven percent of the earth's water is found in the ocean, with a salt content of more than 30,000 mg/L. Water, with a dissolved solids (salt) content below about 1000 mg/L, is considered acceptable for a community water supply [11]. The concept of desalination refers to a wide range of processes designed to remove salts from waters of different salinities as collected from different areas see Table 1. All major water sources can be utilized as raw water supply for desalination, except the Dead Sea as considered as one of the saltiest place on earth. Salinity of the raw water affects the efficiency and the economy of the desalination plants: the more saline raw water sources, the costlier are the production.

Table 1. Salt concentrations of different world water sources [12-14]

Water Source or Type	Concentration (g/l, ppt)
Brackish waters	0.5 to 3
North Sea (near estuaries)	21
Gulf of Mexico and coastal waters	23 to 33
Atlantic Ocean	35
Pacific Ocean	38
Persian Gulf/Arabian Gulf	45
Mediterranean Sea	38.6
Red Sea	41
Dead Sea	~300

Global distributions of fresh water production by different feed water types are shown in Figure 2. There is no significant change in the distribution during the past 20 years. Seawater and brackish are main water sources. Wastewater should be more important, but in 2009 only 5% of all raw waters have their direct origin from wastewater system. The potential in reusing wastewater is thus very large since it is a stable and considerable source with relatively low salinity.

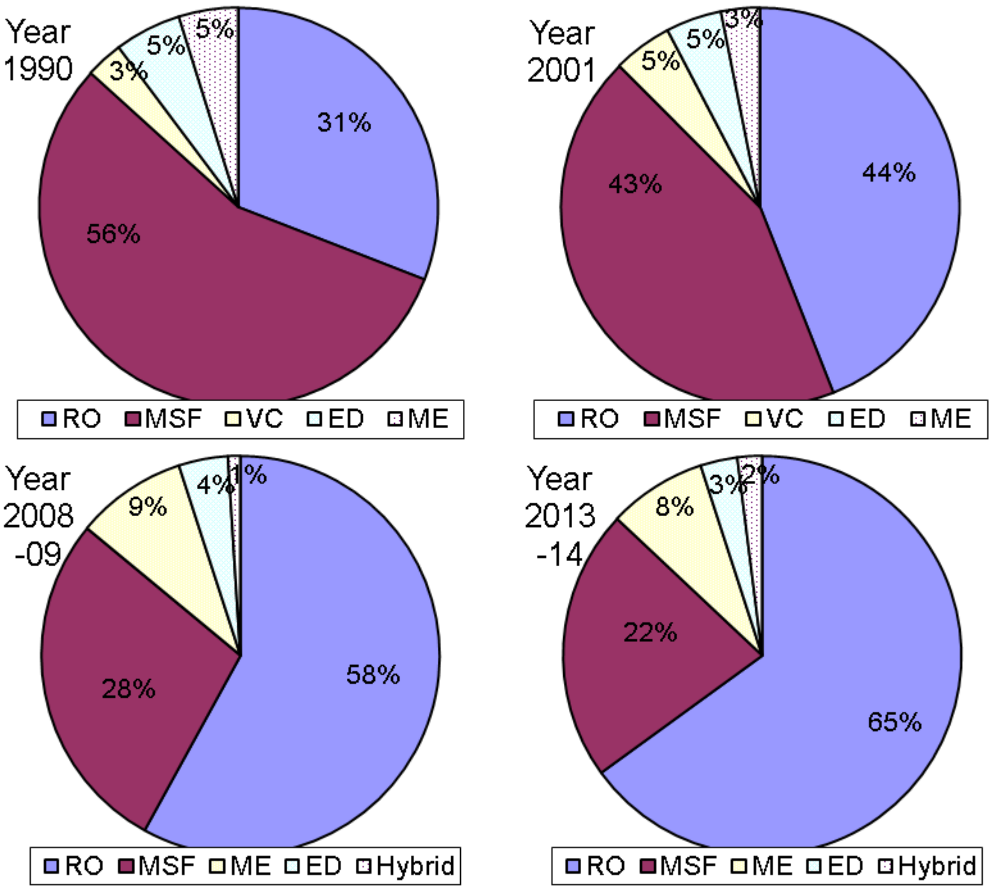

Fig. 1. Global distributions of technologies from year 1990 to in 2013-14 [1,3,10]

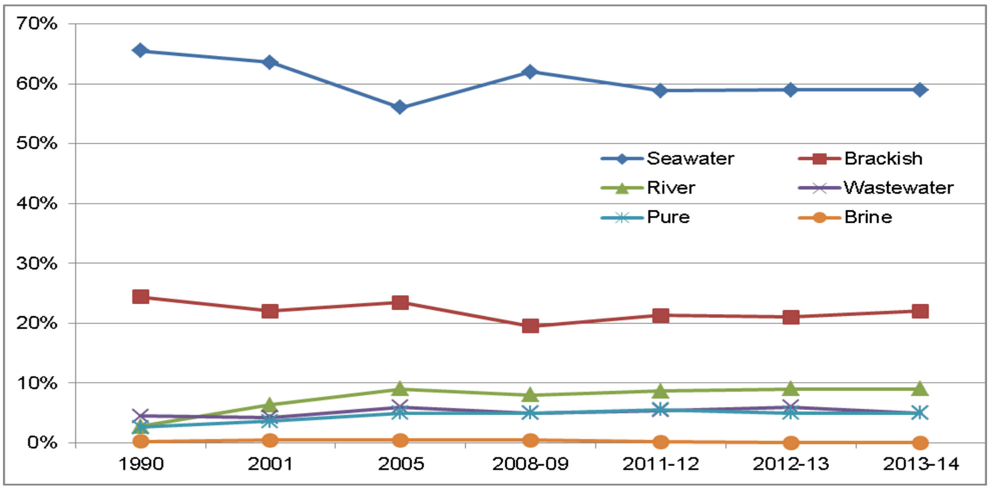

Fig. 2. Global distributions of feed water from year 1990 to in 2013-14 [1,3,10]

The specific energy need for desalination of seawater reverse osmosis (SWRO) has decreased with the development of energy reuse systems. One cubic meter of desalinated water consumes 3.7 kwh of energy, mainly electricity [15]. According to associated document [5], desalination system is divided into two categories 1) conventional source of energy (gas,oil,electricity) and 2) renewable energy sources (wind solar, etc.). Also it can be seen that the desalination relies heavily on fossil fuels (conventional energy), because the cost of fresh water produced from desalination using conventional energy is much lower at present (see Table 2).

2.1. The Cost of Desalination

Despite the lower cost, the utilization of conventional energy has negative impact on environment. Desalination powered by renewable energy sources, as opposed to conventional energy sources, maybe an attractive solution in terms of induced environment impact due to lower conventional energy consumption and lower gas emissions. From the limited nature of conventional energy sources and the impact on the environment point of view, renewable energy sources for desalination have great potential.

Plant size has much impact on desalination cost (see table 3). Thermal methods are more expensive than membrane methods in the approximate scale because of the large quantities of fuel required to vaporize salt water. Systems that use thermal methods have usually large production capacity.

Table 2. Cost of water produced by various energies (excerpted from [5])

Raw water	Type of energy	Cost US$/m^3	Source
Brackish	Conventional	0.26-1.33	[5-8,10-12]
	Photovoltaics	5.6-12.87	[3]
	Geothermal	2.5	[3]
Seawater	Conventional (gas, oil, electricity)	0.44-3.37	[5,6,13,16-18,20,23-32,34-37,41,42]
	Renewable energy:		
	Wind	1.25-6.25	[3,16,19,21,22,39]
	Photovoltaics	3.9-11.25	[15,19]
	Solar collectors	4.37-10.0	[3,14]

Table 3. Cost of water produced by technology type and plant size (excerpted from [5])

Technology	Plant size m^3/d	Cost US$/m^3	Source
MED	<100	2.5-10.0	[3,14]
	12,000-55,000	0.95-1.95	[25,27,28,31]
	>91,000	0.52-1.01	[25,28,29,33-37]
MSF	23,000-528,000	0.52-1.75	[5,27,30,32,34,36]
VC	1000-1200	2.0-2.66	[19,22]
RO: Brackish	<20	5.6-12.87	[3]
	20-1200	0.78-1.33	[9-12]
	40,000-46,000	0.26-0.54	[5,6]
Seawater	<100	1.5-18.75	[3,15,17,18,42]
	250-1000	1.25-3.93	[5,13,16,19]
	1000-4800	0.70-1.72	[5,13,20,22,23]
	15,000-60,000	0.48-1.62	[5,6,24,26,27,29,30,32]
	100,000-320,000	0.45-0.66	[28,34,41]

The operating cost of RO plants has been very much reduced, due to new developments such as: 1) lower-cost, higher- flux, higher salt- rejecting membranes that can efficiently operate at lower pressures and 2) the use of pressure recovery devices [17]. RO and ED are mainly applied for brackish desalination, while ME, VC and MSF are mainly applied for seawater desalination. The VC process was introduced in the 1970s, later than MSF and ME. It was generally used for small- and medium-scale seawater desalination but has been developed rapidly in recent decades [2]. MSF has the lowest production cost for sea water desalination. For brackish water desalination, RO, ED and VC have similar costs, of which ED is the cheapest. ME is the least expensive treatment process for waste water desalination. For brine desalination, ED has the lowest production cost. RO and ME are applied for river desalination, and the cost of RO is much less than ME. The costs of RO and ED for pure water desalination are similar.

3. Desalination in China

China is a serious drought and water shortage country. China is listed as one of thirteen countries that are most water-poor in the world freshwater resource per capita is 1/4 of the world's mean value [18]. Water pollution aggravates the problem. Experts predict that after 2010, China will enter a period of severe water shortage; by 2030, water shortage will reach 60 billion m^3/a. By 2050 this volume is estimated to decrease to around 1700 m^3/a [19].

At present, the main modes of access to fresh water are exploitation of underground water, remote water diversion and desalination, in which the latter is the only method that can increase the total amount of fresh water. In the China littoral resides 40% of the total population of China in the 13 provinces. The population density is very high and the water consumption so large that underground water is exploited [20].

The over-exploitation of groundwater leads to ground subsidence, seawater intrusion, salinization of land and other ecological damage.

To alleviate water depletion in the north of China, the Chinese government developed a plan of remote water diversion called 'South-North water transfer project' in 2002. However the fresh water available from the Yangtze River basin is insufficient and the impact of the water transfer project on the ecosystem is hard to estimate [20].

On the other hand, China has 18,000 km of coastline and 3,000,000 km^2 of ocean areas, which contain abundant seawater [20]. China's population and economy are concentrated in the coastal zone, which makes desalination a viable alternative source of water, as many coastal cities face water shortage [2]. Thus, desalination may be a better method to provide fresh water to these water-shortage areas instead of transferring water from a thousand miles away.

The research on technology of water desalination in China started with ED in 1958, which was the cooperation of navy and Chinese Academy of Sciences; the research on RO started in 1965; the research on large and medium-sized distillation started in 1975. In 1981, the first ED desalination station with capacity 200m^3/day was officially put into operation in Yongxing Island of Xisha (Paracel) Islands [21]. After more than 40 years development, it has made considerable progress and remarkable achievements, gradually forming a comprehensive technology subject and water treatment technology industry [9].

The distribution of installed capacity by plant size and the top 10 plants by capacity is presented. Most of the desalination plants of China are still small and medium scale plants. Large capacity plants only account for 4.7%. Up to 2007, 41% of the desalinated water is used for municipal, 38% for industrial and 21% for power production purposes [10,22]. Installed capacity as per raw water quality is presented. The main water source for desalination is seawater, accounting for 53%, lower than the world's mean value. The proportion of waste water and river as raw water is over the average data of the world. According to preliminary statistics, by the end of June 2006, China has put into operation 41 sea water desalination plants, and the total water production capacity is 12 million m^3/d [23].

From the choice of technology, RO is the most used technology in China and it counts about 75% which is much higher than for world percentage, RO takes up more proportion in China, while MSF is counted almost 7% which is lowers than the world's value [10,22]. RO technology has advantages of low project investment, short construction period, small footprint, easy operation and maintenance, low energy consumption and low cost, which has made it the main desalination technology in China [23]. Reverse osmosis has large edge for municipal water supply. However, for electric power, petrochemical and other enterprises, which require boiler feed water and process water, and produces low-grade steam or heat, MSF has a certain competitive advantage.

Energy consumption should be considered as one of the future parameter for technical and economic indicators for desalination production. In 1997, 500m^3/d reverse osmosis desalination demonstration project" used a turbine-type energy recovery device for the first time, which made desalination energy consumption of fresh water decrease to below 5.5kwh/m^3; In 2000, 1000m^3 / d reverse osmosis desalination demonstration project, built in Changdao of Shandong Province and in Shengsi of Zhejiang Province, used a pressure switching energy recovery device, which made desalination energy consumption of fresh water decrease to below 4.0 kwh/m^3 [23]. Desalination energy consumption indicators have decreased by about 90% (from 26.4 kWh/m^3 to 2.9 kWh/m^3) in 40 years [24]. The utilization of energy recovery and frequency conversion control technology significantly reduces energy consumption of desalination project, leading to accordingly reduction in the production cost. Energy recovery technology and equipment with Chinese independent intellectual property rights have entered the development stage [23]. That will substantially reduce the cost of desalination and promote the development of desalination industry.

In China, seawater is the dominant water source for desalination. Accordingly, its cost should be discussed. Comparing Table 4 with Table 5, it can be observed that the cost of seawater desalination in China also has dropped significantly with time. The cost of RO, MED and VC are lower than the synchronous average value in the world, while the MSF cost is a little higher. The costs are converted into US dollars using exchange rate in respective year. The source of RMB vs. U.S. dollar exchange rate is The People's Bank of China, 1986: 3.4528; 1994: 8.6187; 1997: 8.2898; 2000: 8.2784; 2001: 8.2771; 2002: 8.2769; 2003: 8.2770; 2005: 8.1949; 2009: 6.8389; 2010: 6.8268. Table 4 shows that in 2003, under the same desalination conditions (the same place, period, water quality and scale), the cost of LT-MED is the lowest, while the cost of MSF is the highest. The costs are all below 1.0 \$/m^3, no matter what technology, which are closed to or a little lower than the world's mean value. Up to 2005, the total production cost of seawater desalination by RO is 4.5-5.5 Yuan/m^3 (0.55-0.67\$/m^3), while the cost of desalination by distillation is 5-7 Yuan/m^3 (0.61-0.85\$/m^3) [23].

The reasons for lower desalination cost in China are mainly including 1) lower labour cost; 2) lower energy cost and consumption due to energy reuse systems; 3) lower infrastructure investment because of smaller scale and lower price of commodities. Although the cost for desalination is significantly reduced in past 20 years, it still higher compared to tap water in China. With a continued decrease of desalination cost and an increase in tap water price for residents, desalination will be interesting also for large scale municipal water supply in China [23]. At present, the average cost of seawater desalination has been closed to 5 Yuan/m^3 (0.73 \$/m^3), and the cost brackish water desalination dropped to 2-4 Yuan/m^3 (0.29-0.59 \$/m^3) [24]. Lower price of tap water is the constraint for the development of desalination industry. Table 5 shows some SWRO projects of the desalinated water cost in different countries. It can be seen that the actual cost from 2002 year to 2008 year is always below 1 US \$/m^3 for all desalination projects, which is similar to the estimate trends.

Table 4. The cost of seawater desalination of some desalination plants [10,25]

Project name	Technology	Year	Scale (t/d)	Cost (Yuan/t)/ (\$/m^3)
Changhai county, Dalian	RO	1994	1000	7.31/ 0.85
Shengshan , Zhejiang	RO	1997	500	7.78/ 0.94
Changdao, Shandong	RO	2000	1000	4.09/ 0.49
Huaneng electric power plant, Weihai	RO	2001	2500	5.98/ 0.72
Desalination demonstration project, Tianjin	RO	2003	1000	6.45/ 0.78
Dagang electric power plant, Tianjin	LT-MED	1986	3000	5.71/ 1.65
Huangdao electric power plant, Shandong	LT-MED	2003	3000	5.48/ 0.66
Haizi food company, Tianjin	MSF	2002	6000	7.00/ 0.85

Table 5. Desalinated water cost (US \$/m^3), for different countries in the recent years

Project name & country	Year	Price (US \$/m^3)	Source
Carboneras SWRO Project – Spain	2002	0.57	[22]
Ashkelon (SWRO) Project – Israel	2005	0.53	[22]
Dhekelia, Cyprus (rehab)	2007	0.88	[10]
Fujairah 2, UAE	2007	0.85	[10]
Tianjin, China	2007	0.95	[10]
Palmachim SWRO Project –Australia	2007	0.78	[22]
Ras Laffan B (IWPP)–Qatar	2008	0.80	[22]
Hamma (SWRO) Algiers, Algeria	2008	0.82	[22]
Palm Jumeirah Reuse – Dhabi, U.A.E.	2008	0.33	[21]
Palmachim, Israel (update)	2008	0.78	[10]
Tuas, Singapore (update)	2008	0.57	[10]

Independent Water Power Project (IWPP); Seawater Reverse Osmosis (SWRO)

4. Results and Discussions

4.1. Estimation and analysis

In Figure 4, the downward trend in the cost of seawater desalination is clear, no matter what kind of process. From 2015 to 2020, the trend lines are all close to straight, with the average value tending to US \$ 0.5. The cost of MSF is the lowest compared to other four technologies. Figure 5 shows that the cost of waste desalination using RO, VC, and ED technology is gradually decreasing. The trend lines predict that the cost of VC is the lowest of the three technologies for waste desalination after 2000. The average cost value indicates towards US \$ 0.3 from 2015 to 2020. Figure 6 shows that the cost trends of RO and ED for different water sources desalination. Before 2001, the cost of RO and ED for brackish desalination is higher than that for pure and river. After 2010, the cost of RO for river desalination is the highest, while the cost of RO for pure desalination is the lowest. From 2005 to 2010, the average cost tends to 0.3 \$ /m^3, while from 2015 to 2020 it decreases to 0.2 \$ /m^3. During the same period, for the same water source desalination, the costs of RO and ED are similar.

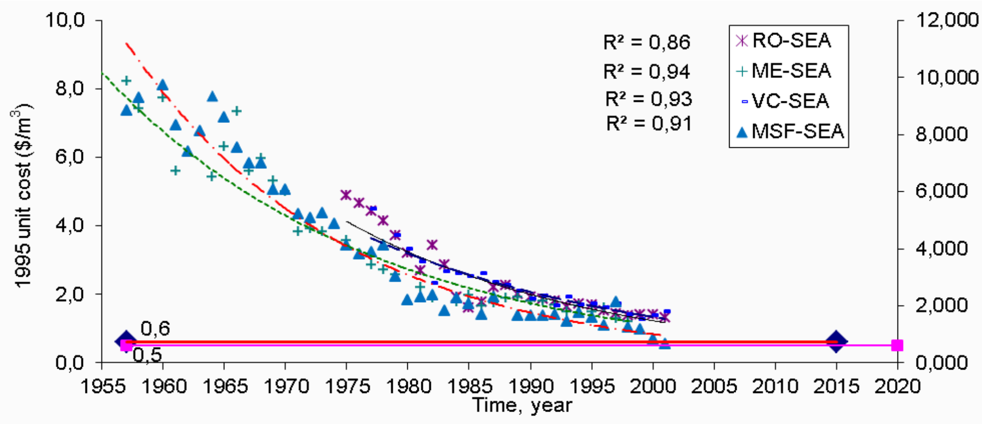

Fig. 4. Average unit cost of seawater desalination by different technologies

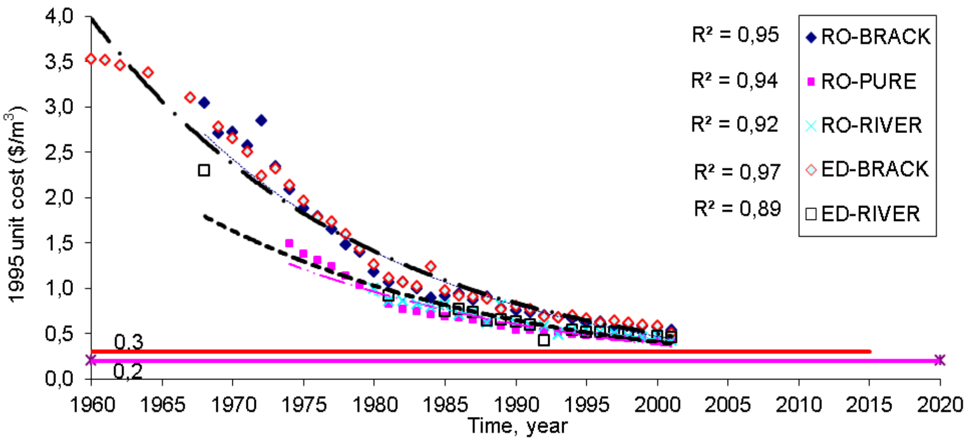

Fig. 5. Average unit cost of waste water desalination by different technologies

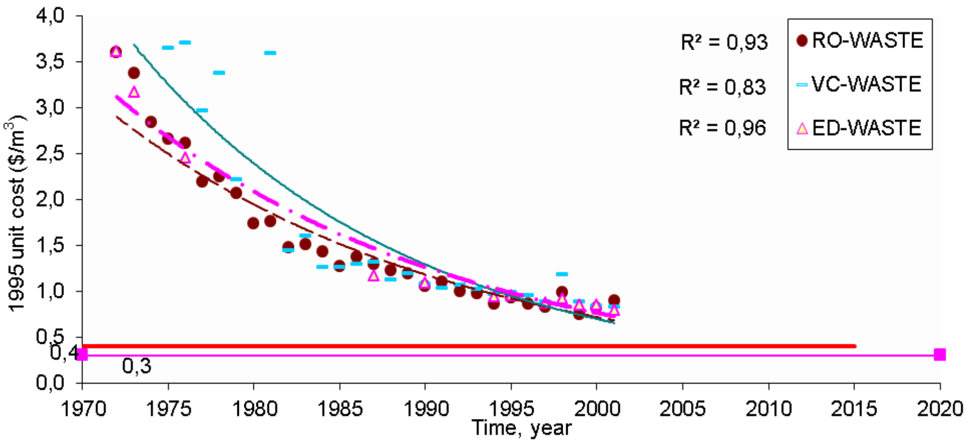

Fig. 6. Average unit cost of different water sources desalination by RO and ED

4.2. Discussions

Even if the overall cost decreased a lot, desalination is still more expensive than regular water supply. The price is one of the major restrict to the development and application. As mentioned above, the desalination cost is influenced by a variety factors, mainly including technology, feed water, energy and capacity. The results of estimation shows that slopes of all the cost trend lines, whatever technologies or feed water, are gradually decrease. That means the decreased trends will be more and more slowly. It will stop decrease and keep stable around year 2020, even increase due to the limited energy, only if there is new development of technology or costly energy. The main impact factors on desalination cost are discussed as following. As can be seen from statistic data, RO has become the most applied technology instead of MSF, since the later need to cost large amount of energy.

However, both from the estimate results and the actual data, we can see that RO doesn't have obvious cost advantage. Thus, the improvement of membrane performance is the most effective method to reduce the cost for membrane system. One aspect of improvement is lower membrane resistance. That can reduce the operating pressure required, which means less energy input and less operation cost. Another aspect is the improvement of the anti-pollution performance. That can extend the membrane life and cleaning period, which reduce the drug consumption the cost for membrane replacement. MSF has the cost advantage for seawater desalination. However, the superiority will be reduced by the limited conventional energy. Increasing of shortage conventional energy and the more applied alternative energy will lead to the higher price, which means the cost for MSF will increase more than membrane technology, as MSF needs more energy input. The share of MSF will continue to decrease. Since MSF can produce better quality water with less salt, it is more suitable for some special industries.

Every technology has its own applicable conditions. We can't conclude which one is the best or worst. In fact we can see that, despite improvement of performance, choose suitable technology according to the feed water, capacity and local situation is another way to reduce cost. The selection of feed water depends on local condition, and influence the technology, energy and cost. Seawater is not most costly, but the most amount source. Wastewater as feed water is used modestly, but gradually it should grow in importance as it is a stable and large amount water source with less salinity. It has the lower cost than seawater. However, since there is more pollutant, toxic and hazardous substances than other feed water types, the health risk is the potential problem and constrain for wastewater desalination. Rivers and pure water are both have lower salinity and cost than most water types, but desalination still more expensive than regular water treatment process. That's the reason why these two kinds of feed water used less even if they are cheaper. Thus the desalted water from rivers and pure water could be only used in some special industries which require better water quality.

Increased desalination capacity means increased energy input. At this stage, desalination relies heavily on fossil fuels. But in view of finite reserves of non-renewable resources and negative impact on environment when using fossil fuels, the alternative energy sources have great development potential which needs to be understood better for the future. Alternative energy, which includes nuclear energy and renewable energy, such as solar, wind, geothermal energy and so on, is clean energy compared to fossil fuels. However, according to the study by Tian (2001), nuclear energy, which causes less environment problems, has economic competitiveness compared to fossil energy when it is applied in RO, MSF and MED [27]. The issue of this kind of energy is the safety of nuclear reactor and how to control the nuclear waste.

The increasing consumption of conventional energy and applied renewable energy probably increase the cost in the future. The total cost will stop decreasing and even increase due to the energy issue. In addition to develop more costly energy, the improvement of energy recovery technology is another effective method to reduce the energy cost.

4.3. Discussions about desalination in China

China counts the first world population of more than 20% of the global population. Thus, the available shortage of fresh water can be supplied through desalination as one option in the form of sea water reverse osmosis (SWRO). The recent study was obtained that half of China's GDP is earned in water scarce provinces [28]. This initiative resulted in the construction of two 100,000 m^3/day facilities, the Qingdao and Tianjin Dagang SWRO desalination facilities. In July 2009, Tianjin's 100,000 m^3/day, seawater reverse osmosis plant began delivering desalinated water to the Tianjin's industrial zone and 36 months later another 100,000 m3/day of water was being injected into Qingdao's municipal water supply [29].

The development of desalination has been fast in China for the last 15 years, especially seawater desalination. That's the same periods that water shortage and deterioration of water environment increasing. For China, the population and economy concentrate in the coastal zone, where is serious short of fresh water. It is necessary and feasible to develop desalination to relieve the pressure of water shortage in China.

Since the price for desalination is much higher than regular water supply, the users and demands is not so much. Most of the plants are medium or small scale. In addition, China also faces energy shortage. That's why RO is more popular than MSF in China. For some cases, MSF even has higher cost than RO, since it consumes more energy. However, the quality of domestic membrane is a big issue. Up to now, domestic membrane takes up little proportion, as it has poorer performance than imported membrane. The membrane for RO is mainly imported from abroad, which has a higher price than the domestic one. Thus, for China, independent research and development of domestic membrane with higher performance is a major way to reduce the cost for desalination by membrane process.

Increasing the proportion of feed water with less salinity is another way to decrease cost. The brackish proportion in China is lower than the mean value worldwide. It should be used more. Another important water source is urban wastewater, since the urban are the major areas serious shortage of fresh water. The reclamation and reuse of wastewater can reduce the amount discharge to the receiving water, as well as ease the pressure of water shortage in the urban with concentrated population.

In addition, although it will increase the cost, the increase of using nuclear or renewable energy is special important for China, as it is a country with less conventional energy per capital and deteriorating environment. Thus, the further development of energy recovery systems is crucial to reduce the energy cost.

Besides reducing the desalination cost, the rational water price system is also important to the development of desalination market, which is maybe special for China. The rational price for different water quality is an important policy to keep the competitiveness of desalination. The decrease of the desalination cost and the rational increase of tap water price will make desalination used more widely. Before the price of tap water increases to a rational level, which should be slowly carried out, the government should develop a series of preferential policy to protect and encourage the desalination industry, such as increasing economy input on research and providing subsidy.

In desalination, there are some parameters such can affect the price as technology, device, scale and pollution in water source, this makes the average Chinese seawater desalination cost between 5 to 7 Yuan RMB/m^3, that is higher than the average in the world (0.5 US$/$m^3$) [30]. At the mean time the development of desalination should be at freely discussed by the government in order to have more projects and reduces the impacts of desalination on marine environment and biological life. Helpful studies and researches for environmental protections were carried out for the concentrated brine water and how it can be discharge to the ocean with new characteristics than the offshore water, such as temperature, pH and salinity, and adversely impact on marine life [31–33].

5. Conclusion

In this paper, the future desalination cost trends is estimated using least-square fitting methods. Statistical analysis indicates a total production cost of less than US 0.5 $/$m^3$ in 2020. This will probably continue to drop due to effects of scale and reach US 0.35 $/$m^3$ after year 2020. Wastewater, which is an important source for desalination in urban area, is less costly to desalinate, approximately US 0.3 $/$m^3$ from the year 2015. Brackish water will reach US 0.2 $/$m^3$ at year 2015. After 2020, the cost decrease speed will be lower and reach a stable value. We have to find better solution for the constraints to reduce the desalination cost.

The major impact factors of cost are discussed. MSF has the lowest cost of technologies for seawater desalination, but the superiority will be reduced due to increase of energy price in the future. RO process has great advantages over other processes. It has become the major technology with most installed capacity instead of MSF. The improvement of membrane performance is the main way to reduce the cost. The improvement of energy efficiency and the development of energy recovery systems are important ways to reduce energy consumption.

When compare to China, there is feasibility and necessity to develop desalination, especially in the eastern coastal regions. From the perspective of market demands and desalination industry, China is still at the primary stage but recently trying to follow the market of desalination. The main reason is the higher price than other ways of water supply. Thus, the reduction of cost is the main points to stimulate market demands. In addition to the aspects discussed above for reducing cost, the establishment of rational water price system is another way to improve the competitiveness and promote the development of desalination in China.

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